Proceedings
of the
Indiana Academy of Science

VOLUME 113 2004 NUMBER 2

PROCEEDINGS OF THE INDIANA ACADEMY OF SCIENCE

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Cover photo: The cover shows *Galerina autumnalis*, a wood decay (lignicolous) fungus, common from late fall to early spring in woodlands in Indiana. The cap, 2–7 cm across, is dark brown when moist, but fades on drying giving it an irregular water-soaked appearance as seen here. This seemingly unintrusive mushroom is responsible for a number of mushroom poisonings in the United States. It contains the deadly cyclopeptides known as amanitins, the same toxins found in the destroying angel, *Amanita virosa* and the death cap, *Amanita phalloides*. (Photo by Don Ruch)

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Publication date: 21 December 2004

This paper meets the requirement of ANSI/NISO Z39.48-1992 (Permanence of Paper).

ISSN 0073-6767

2004. Proceedings of the Indiana Academy of Science 113(2):99–108

RECENT MACROMYCETES RECORDS FROM THREE EAST-CENTRAL INDIANA COUNTIES

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ABSTRACT. The Smith Great Lake States Foray was held in east-central Indiana in Fall 2002. Since participants of the foray included professional mycologists from the Great Lake States, this provided an opportunity to significantly increase our knowledge of macromycetes (both ascomycetes and basidiomycetes) distribution in Indiana. A total of 108 collections was made from Ginn Woods (Delaware County), Camp Windigo (Grant County), and Wilbur Wright Fish and Wildlife Area (Henry County). Species collected from Camp Windigo and Wilbur Wright Fish and Wildlife Area represent new county records. The 12 collections at Camp Windigo included two ascomycetes, nine basidiomycetes, and one slime mold, while the 16 collections at WWFWA included two ascomycetes and 14 basidiomycetes. Of the 80 collections from Ginn Woods, 53 represent new county records. The 80 collections included six ascomycetes, 73 basidiomycetes, and one mitosporic (imperfect) fungus. None of the species reported from the three sites were unexpected based on general region of distribution for each species.

Keywords: Macromycetes, basidiomycetes, ascomycetes, mushrooms, Great Lake States Foray, Delaware County, Grant County, Henry County, Indiana, Ginn Woods, Camp Windigo, Wilbur Wright Fish and Wildlife Area

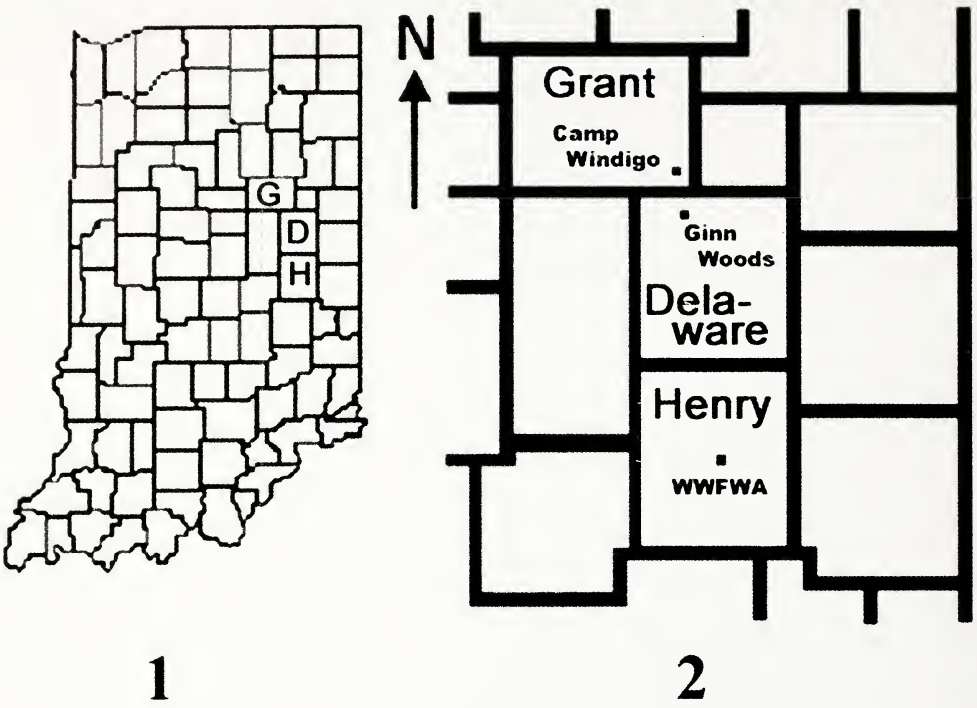
In an earlier paper Ruch et al. (2001) reported that our knowledge of macromycetes (both basidiomycetes and ascomycetes) in Indiana is wanting. A survey of the various herbaria within the state revealed that only nine contained fungal specimens, with most having fewer than 400 collections. Since that report, no additional information has been published.

In the Fall of 2002, I had the opportunity to host the Smith Great Lake States Foray. This foray, often referred to as the "Smith Foray" in honor of Alexander H. Smith, former mycologist at the University of Michigan, is an annual event held each year since 1974. Attendees include professional mycologists and their students, along with other interested scientists, both professional and amateur. The foray offered an opportunity to expand our knowledge of macromycetes occurrence and distribution in east-central Indiana. The purpose of this paper is to list the fungi collected and identified during the Smith Foray. Additional collections not reported previously from Ginn Woods between 1994 and 2001 have also been included.

STUDY SITES

Fungi were collected from three localities: Camp Windigo in Grant County, Ginn Woods in Delaware County, and Wilbur Wright Fish and Wildlife Area (WWFWA) in Henry County (Figs. 1, 2). Camp Windigo, a Girl Scout camp in southeastern Grant County, served as the home base. The foray occurred from 19–22 September. Following is a short description of each site.

Ginn Woods, Delaware County: Ginn Woods, a typical flatwoods, lies in the Bluffton Till Plain section of the Central Till Plain Natural Region (Homoya et al. 1985). The woods is a deciduous forest community and, based on structure composition and size, is the second largest old-growth stand in Indiana (Badger et al. 1998). The shade-tolerant species *Acer saccharum* Marshall, *Fagus grandifolia* Ehrh., and *Tilia americana* L. dominate both the under- and overstories. Subdominant species include *Aesculus glabra* Willd., *Celtis occidentalis* L., *Fraxinus americana* L., *Prunus serotina* Ehrh., *Quercus rubra* L., and *Ulmus rubra* Muhl. In localized areas where soil drainage is poorest, *Acer saccharinum* L., *Acer rubrum* L., *Carya laciniosa* (Michx. f.) Loudon, *Fraxinus lanceolata* Borkh., *Platanus occidentalis* L., and *Populus deltoides* Marshall are prominent. The soils of Ginn Woods are somewhat poorly to very



Figures 1, 2.—Location of the three collecting sites for the 2002 Smith Great Lake States Foray. 1. State map showing the location of Grant County (G), Delaware County (D), and Henry County (H) in east-central Indiana; 2. Enlargement of east-central Indiana showing the location of Camp Windigo in Grant County, Ginn Woods in Delaware County, and Wilbur Wright Fish and Wildlife Area in Henry County.

poorly-drained and seasonal ponding typically occurs on low-lying portions (Huffman 1972).

Wilbur Wright Fish and Wildlife Area (WWFWA), Henry County: WWFWA lies within the eastern third of the Tipton Till Plain Section of the Central Till Plain Natural Region (Homoya et al. 1985), also known as the Castle Till Plain and Drainageway of the Central Till Plain Natural Region (Gray 2000). The woods of Unit 2 occur on morainic deposits from the Knightstown Morainic System, formerly known as the Champaign Morainic System (Indiana Geological Survey 2001; Malott 1922; Wayne 1965). The soils of Unit 2 are mostly Losantville silt loam, are of medium to moderately fine texture, and are usually well-drained (Hillis & Neely 1986). The woods is a deciduous forest community; and the trees comprising the under- and overstories include *Carya cordiformis* (Wangenh.) K. Koch, *Carya ovata* (Miller) K. Koch, *Fagus grandifolia*, *Fraxinus americana*, *Juglans nigra* L., *Liriodendron tulipifera* L., *Quercus alba* L., *Quercus rubra*, *Acer saccharum*, *Aesculus glabra*, *Tilia americana*, *Carya glabra* (Miller) Sweet, *Carpinus caroliniana* Walter, and *Ostrya virginiana* (Miller) K. Koch (Ruch et al. 2002).

Camp Windigo, Grant County: The woods at Camp Windigo, which are typical flatwoods, lie in the Bluffton Till Plain section of the Central Till Plain Natural Region (Homoya et al. 1985). The soils at the camp are of the Fox series, mostly Fox silt loam, and are typically moderately well-drained, although some evidence of season ponding was evident (Jensen 1988). The woods are a deciduous forest community and the trees comprising the under- and overstories include *Quercus rubra*, *Quercus alba*, *Acer saccharum*, *Carya cordiformis*, *Carya ovata*, *Fraxinus americana*, *Ulmus rubra*, *Celtis occidentalis*, and *Aesculus glabra*.

WEATHER IN 2002

From 1 January to 30 June 2002, Muncie, Indiana received 57.9 cm (22.78 inches) of

rain, 28% above the average rainfall of 45.3 cm (17.85 inches). However, rainfall for the two and one-half months prior to the foray was below normal. From 1 July to 19 September, Muncie, Indiana received only 13.9 cm (5.49 inches) of rain, 42% below the average rainfall of 23.8 cm (9.36 inches). The first 19 days of September were especially dry, receiving only 1.1 cm (0.44 inch) of rain instead of the anticipated 4.8 cm (1.89 inches).

METHODS

At all sites participants randomly crisscrossed the woods. No efforts were made to systematically cover any of the sites. Specimens were collected, wrapped separately, and brought to the central collecting site at Camp Windigo for identification. Following identification, specimens were dried on several Excalibur food dehydrators, then given a Ball State Mushroom Herbarium number (BSUHM #) and placed in the herbarium. The primary sources used to identify the mushrooms included (in alphabetical order) Arora (1986), Barron (1999), Bessette et al. (1995, 1997, 2000), Breitenbach & Kranzlin (1986, 1991, 1995, 2000), Dennis (1981), Gilbertson & Ryvarden (1986), Hesler (1967, 1969), Hesler & Smith (1979), Huffman et al. (1989), Lincoff (1991), Martin (1969), Miller (1979), Moser (1983), Phillips (1991), Roody (2003), Smith (1947), and Smith & Thiers (1971).

RESULTS

The macromycetes, both ascomycetes and basidiomycetes, that were collected and identified at all three sites of the Smith Great Lake States Foray are listed in the Appendix. In addition, macromycetes collected in Ginn Woods between 1994 and 2001, and not previously reported, are also listed in the Appendix. Each species report contains the following information: (1) scientific name; (2) taxonomic synonyms, if appropriate; (3) common names, if any; (4) county/counties of collections (see Study Sites); and (5) the BSUHM herbarium number(s). Specimens with a GMM number are in Gregory Mueller's collection at The Field Museum, Chicago, Illinois. Species that have been previously reported for Ginn Woods by Ruch et al. (2001) are indicated by an asterisk (*). Species collected at Ginn Woods by Donald Ruch between 1994–2001, but not previously reported, are indicated by a pound sign (#). Species are listed following the taxonomic scheme in Hawksworth et al. (1995).

During the 2002 Smith Great Lake States Foray, a total of 108 collections was made, including 80 from Ginn Woods, 12 from Camp Windigo, and 16 from Wilbur Wright Fish and Wildlife Area (WWFWA). All species collected from Camp Windigo and WWFWA represent new county records. The 12 species collected at Camp Windigo included two ascomycetes, nine basidiomycetes, and one slime mold, while the 16 species collected at WWFWA included two ascomycetes and 14 basidiomycetes. Of the 80 collections made at Ginn Woods, 53 represent new records, while 27 were species that had been reported earlier (Ruch et al. 2001). The 80 collections by participants of the foray included six ascomycetes, 73 basidiomycetes, and one mitosporic (imperfect) fungus.

DISCUSSION

Because the weather was so dry in the second half of 2002, especially in September, the number of species collected was much less than anticipated. Even so, of the 108 collections made, 81 represent county records, e.g., 53 from Delaware County, 12 from Grant County, and 16 from Henry County.

By combining all results from Ginn Woods, e.g., the Smith Foray collections, the additional collections from 1994–2001 listed in this paper, and previous collections reported by Ruch et al. (2001), the total recorded species, and hence Delaware County records, are 136. These records include 13 ascomycetes, 119 basidiomycetes, 3 slime molds (myxomycetes), and 1 mitosporic (imperfect) fungus, together representing 91 genera from 43 families and 23 orders.

Of all of the macromycetes reported from Delaware, Grant, and Henry counties, none were unexpected. This assertion is based on species distribution given in the monographs and popular field guides listed in the Methods section. Most of the authors of these sources have taken the extreme eastern, western, northern and southern known sites (often states) of collections for a species, then assumed that the species occurs in all areas in between, whether records exist or not. Thus, the species of fleshy fungi reported herein were expected; but this is the first report that

includes voucher specimens of these fungi from Delaware, Henry, and Grant counties.

ACKNOWLEDGMENT

I wish to acknowledge and extend my thanks to the Girl Scouts of Wapehani Council, Inc. for permitting us to use the facilities and grounds at Camp Windigo, Upland, Indiana. I also wish to thank the Ball State Weather Station, especially Dr. David Arnold, director, and Tricia Childers and Lindsey Butor, Observers, for providing rainfall data for 2002. I particularly wish to extend my sincere appreciation to the participants of the 2002 Smith Great Lake States Foray for their contribution to increasing our knowledge of macromycetes occurrence and distribution in east-central Indiana. The participants of the foray were (in alphabetical order) Gerard Adams, Michigan State University; Josh Burgess, University of Wisconsin–La Crosse; Darrell and Carol Cox, University of Illinois; Michael Foos, Indiana University East; Robert Gessner, Western Illinois University; Martin Gilmore, Ball State University; Heather Hallen, Michigan State University; Dorothy McMeekin, Michigan State University; Andrew S. Methven, Eastern Illinois University; Drew Minnis, Southern Illinois University; Gregory Mueller and Betty Strack, The Field Museum in Chicago; Paul Olexia, Kalamazoo College; Bernadette O'Reilly, University of Wisconsin-La Crosse; John Rippon, University of Chicago, Emeritus; Donald and Brenda Ruch, Ball State University; John Steinke, Wisconsin Mycological Society; Walter Sundberg, Southern Illinois University; Michael R. Tansey, Indiana University; and Thomas J. Volk, University of Wisconsin–La Crosse.

APPENDIX
Catalog of Macromycetes
(Delaware, Grant, and Henry Counties, Indiana)

Macromycetes collected during the 2002 Smith Great Lake States Foray and from Ginn Woods between 1994 and 2001, and not previously published, are listed here. Each species report contains the following information: (1) scientific name; (2) taxonomic synonyms, if appropriate; (3) common names, if any; (4) county/counties of collections (see Study Sites); and (5) the BSUHM herbarium number(s). A GMM number indicates that the specimen is in Gregory Mueller's collection at The Field Museum, Chicago, Illinois. Species that have been previously reported for Ginn Woods by Ruch et al. (2001) are indicated by an asterisk (*). Species collected at Ginn Woods by Donald Ruch between 1994–2001, but not previously reported, are indicated by a pound sign (#). Species are listed following the taxonomic scheme in Hawksworth et al. (1995).

PHYLUM ASCOMYCOTA

(CALICIALES)

Mycocaliciaceae

Phaeocalicium polyporaeum (Nylander) Tibell on *Trichaptum biforme* (Fries) Ryvarden. Delaware County. BSUHM 375.

(HYPERCREALES)

Hypocreaceae

Hypomyces chrysospermus Tulasne & C. Tulasne (on a bolete); Synonym: *Apiocrea chrysosperma* Tulasne & C. Tulasne. Common names: Bolete Mold, Golden Hypomyces, Bolete Eater. Grant County. BSUHM 376.

(LECANORALES)

Physciaceae

Physcia aipolia (Ehrhart : Humpe) Fürnrohr. Common names: Hoary Rosette Lichen, Hoary Physcia. Henry County. BSUHM 377.

(LEOTIALES)

Leotiaceae

Bisporella citrina (Batsch : Fries) Korf & Carpenter*; Synonyms: *Calycella citrina* (Hedwig) Boudier, *Helotium citrinum* Fries. Common names: Yellow Fairy Cups, Orange Wood Cup. Delaware County. BSUHM 378.

Crinula caliciiformis (Fries) Fries. NOTE: *Crinula caliciiformis*, an erect club-shaped asexual stage, is the anamorph of *Holwaya mucida* (Schulzer) Korf & Abawi, a saucer-shaped sexual stage. *Holwaya* is in the Leotiaceae. Delaware County. BSUHM 379.

Hymenoscyphus fructigenus (Bulliard : Fries) S.F. Gray. Common names: Acorn Cup, Nut Disco. Delaware County. BSUHM 476.

Sclerotiniaceae

Ciboria peckiana (Cooke) Korf; Synonyms: *Rutstroemia macrospora* (Cooke) Korf, *Rutstroemia macrospora* (Peck) Kanouse. Common name: Common Wood Ciboria. Delaware County. BSUHM 380.

(PEZIZALES)

Otideaceae

Scutellinia scutellata (Linnaeus : Fries) Lambotte; Synonym: *Peziza scutellata* Linnaeus : Fries.

Common names: Eyelash Cup, Molly Eye-winker, Eyelash Pixie Cup. Henry County. BSUHM 381.

Sarcoscyphaceae

Sarcoscypha occidentalis (Schweinitz) Saccardo. Common name: Stalked Scarlet Cup. Grant County. BSUHM 382.

(RHYTISMATALES)

Rhytismataceae

Rhytisma acerinum (Persoon) Fries. Common name: Tar Spot of Maple. Delaware County. BSUHM 383.

PHYLUM BASIDIOMYCOTA

(AGARICALES)

Agaricaceae

Agaricus peculator Murrill#; Synonym: *Agaricus placomyces* Peck. Delaware County. BSUHM 58.

Lepiota cristata (Albertini & Schweinitz : Fries) Kummer#; Synonym: *Leucoagaricus cristata* (Albertini & Schweinitz : Fries) Kummer. Common names: Stinking Parasol, Malodorous Lepiota, Crested Lepiota, Brown-eyed Parasol, Stinking Dapperling. Delaware County. BSUHM 59, 95.

Lepiota procera (Scopoli : Fries) S.F. Gray#; Synonyms: *Macrolepiota procera* (Scopoli : Fries) Singer, *Leucocoprinus procerus* (Scopoli : Fries) Patouillard. Common names: Parasol Mushroom, Parasol. Delaware County. BSUHM 51.

Melanophyllum echinatum (Roth : Fries) Singer; Synonyms: *Melanophyllum haematospermum* (Bulliard) Kreisel, *Lepiota haematosperma* (Bulliard : Fries) Quélet. Common name: Red-gilled Agaric. Delaware County. BSUHM 384.

Amanitaceae

Amanita flavorubescens Atkinson#; Synonym: *Amanita flavorubens* Berkeley & Montagne. Common name: Yellow Blusher. Delaware County. BSUHM 63, 64.

Amanita vaginata (Bulliard : Fries) Vittadini#; Synonym: *Amanitopsis vaginata* (Bulliard : Fries) Roze. Common names: Grisette, Gray Flocet, Gray Pusher. Delaware County. BSUHM 98.

Coprinaceae

Coprinus insignis Peck#. Delaware County. BSUHM 94, 102.

Psathyrella velutina (Persoon : Fries) Singer#; Synonym: *Lacrymaria velutina* (Persoon : Fries) Konrad & Maublanc. Common names: Weeping Widow, Velvety Psathyrella. Delaware County. BSUHM 62.

Pseudocoprinus disseminatus (Persoon) Kühner; Synonyms: *Coprinellus disseminatus* (Persoon) Lange, *Coprinus disseminatus* (Persoon) S.F. Gray, *Psathyrella disseminata* (Persoon : Fries) Quélet. Common names: Non-inky Coprinus, Little Helmets. Delaware County. BSUHM 385.

Psathyrella candolleana (Fries) Maire; Synonym: *Hypholoma appendiculum* Bulliard. Common names: Common Crumble Cap, Common Psathyrella, Suburban Psathyrella. Delaware County. BSUHM 386.

Entolomataceae

Entoloma abortivum (Berkeley & Curtis) Donk#; Synonym: *Clitopilus abortivus* Berkeley & Curtis. Common names: Aborted Entoloma, Aborted Pinkgill. Delaware County. BSUHM 90, 91, 338.

Pluteaceae

Pluteus cervinus (Schaeffer) Kummer*; Synonym: *Pluteus atricapillus* (Batsch) Fayod. Common names: Deer Mushroom, Fawn Mushroom, Fawn-colored Pluteus, Fawn Shield-Cap. Delaware County. BSUHM 387.

Pluteus longistriatus Peck. Common name: Pleated Pluteus. Delaware County. BSUHM 388.

Strophariaceae

Pholiota albocrenulata (Peck) Saccardo.* Delaware County. BSUHM 389.

Tricholomataceae

Armillaria tabescens (Scopoli) Emel*; Synonym: *Armillariella tabescens* (Scopoli) Singer. Common name: Ringless Honey Mushroom. Delaware County. BSUHM 390.

Cheimonophyllum candidissimum (Berkeley & Curtis) Singer. Common name: White Oysterette. Delaware County. BSUHM 391.

Clitopilus prunulus (Scopoli : Fries) Kummer.=. Common names: Sweetbread Mushroom; The Miller (because it has the smell of flour). Delaware County. BSUHM 46, 71.

Crinipellis zonata (Peck) Patouillard; Synonym: *Collybia zonata* Peck. Common names: Zoned-cap Collybia, Zoned Crinipellis. Delaware County. BSUHM 392.

Gymnopus biformis (Peck) Halling; Synonym: *Collybia biformis* (Peck) Singer. Delaware County. BSUHM 393.

Gymnopus dryophilus (Bulliard : Fries) Murrill; Synonym: *Collybia dryophila* (Bulliard : Fries) Kummer. Common name: Oak-loving Collybia. Delaware County and Henry County. BSUHM 29, 184, 477, 478.

Gymnopus subnudus (Ellis : Peck) Halling; Synonym: *Collybia subnuda* (Ellis : Peck) Gilliam. Delaware County. BSUHM 394.

Hohenbuehelia angustata (Berkeley) Singer. Delaware County. BSUHM 395.

Laccaria ochropurpurea (Berkeley) Peck=; Synonym: *Clitocybe ochropurpurea* (Berkeley) Saccardo. Common names: Purple-gilled Lascaris, Purple-

ochre Tallowgill. Delaware County. BSUHM 55, 67, 68, 69.

Marasmiellus nigripes (Schweinitz) Singer; Synonym: *Heliomyces nigripes* (Schweinitz) Morgan. Common name: Black-footed Marasmius. Delaware County. BSUHM 396.

Marasmius delectans Morgan. Delaware County. BSUHM 397.

Marasmius pyrrhocephalus Berkeley; Synonym: *Rhizomarasmius pyrrhocephalus* (Berkeley) Petersen. Delaware County. BSUHM 398.

Marasmius rotula (Scopoli : Fries) Fries. Common names: Collared Parachute, Collared Horsehair, Pinwheel Marasmius, Little Wheel. Delaware County. BSUHM 43, 479.

Marasmius siccus (Schweinitz) Fries.* Common names: Orange Pinwheel, Orange Pinwheel Marasmius, Dry Marasmius. Delaware County. BSUHM 399.

Mycena corticola (Fries) Gray. Delaware County. BSUHM 400.

Mycena floccipes (Fries) Kühner; Synonym: *Hydropus floccipes* (Fries) Singer. Delaware County. BSUHM 401.

Mycena haematopus (Fries) Quélet*; Synonyms: *Mycena haematopus* (Persoon : Fries) Kummer, *Mycena haematopoda* (Persoon : Fries) Kummer. Common names: Bleeding Mycena, Blood-foot Mushroom, Burgundy-drop Bonnet. Delaware County. BSUHM 402.

Mycena luteopallens (Peck) Saccardo*. Common name: Walnut Mycena. Delaware County and Henry County. BSUHM 403, 404.

Omphalina epichysium (Persoon) Quélet. Delaware County. BSUHM 405.

Omphalotus olearius (De Candolle : Fries) Singer; Synonyms: *Omphalotus illudens* (Schweinitz) Saccardo, *Clitocybe illudens* (Schweinitz : Fries) Saccardo. Common names: Jack O'Lantern Mushroom, False Chanterelle. Grant County and Henry County. BSUHM 406, 407.

Panellus stypticus (Bulliard : Fries) Karsten*; Synonyms: *Panellus stipticus* (Bulliard : Fries) Karsten; *Panus stipticus* Fries. Common names: Luminescent Panellus, Bitter Oyster. Delaware County and Henry County. BSUHM 408, 409.

Rhodotus palmatus (Bulliard : Fries) Maire*; Synonym: *Pleurotus subpalmatus* Fries. Common name: Netted Rhodotus. Delaware County and Grant County. BSUHM 410, 411.

Tricholomopsis decora (Fries) Singer; Synonym: *Tricholoma decorum* (Fries) Quélet. Common names: Prunes and Custard, Decorated Mop. Delaware County. BSUHM 412.

Xeromphalina tenuipes (Schweinitz) A.H. Smith; Synonym: *Collybia tenuipes* Schweinitz. Delaware County. BSUHM 413.

Xerula furfuracea (Peck) Redhead, Ginns, & Shoemaker*; Synonyms: *Collybia radicata* var. *furfuracea* Peck, *Oudemansiella radicata* (Relhan) Singer. Common names: Rooting Collybia, Rooted Agaric, Rooted Oudemansiella. Delaware County. BSUHM 414.

Xerula megalospora (Clements) Redhead, Ginns, & Shoemaker; Synonym: *Collybia radicata* var. *pusilla* Peck. Common names: Rooted Collybia, Lesser Rooting Xerula. Delaware County. GMM 6798.

(ATRACTIELLALES)

Phleogenaceae

Phleogena faginea (Fries) Link. Delaware County. BSUHM 415.

(AURICULARIALES)

Auriculariaceae

Auricularia auricula (Hooker) Underwood*; Synonyms: *Auricularia auricula-judae* (Fries) Schroeter, *Hirneola auricula-judae* (Linnaeus) Berkeley. Common names: Jelly Ear, Jew's Ear, Juda's Ear, Wood Ear, Tree Ear. Delaware County. BSUHM 416.

(BOLETALES)

Gyrodontaceae

Gyrodon merulioides (Schweinitz) Singer#; Synonyms: *Boletinellus merulioides* (Schweinitz) Murrill, *Boletinus porosus* (Berkeley) Peck. Common names: Ash-tree Bolete, Shallow Pore Bolete. Delaware County. BSUHM 38.

Gyroporus castaneus (Bulliard : Fries) Quélet#. Synonym: *Boletus castaneus* Fries. Common name: Chestnut Bolete. Delaware County. BSUHM 45.

Strobilomycetaceae

Tylopilus indecisus (Peck) Murrill#; Synonym: *Boletus indecisus* Peck. Common names: Indecisive Bolete, Question Bolete. Delaware County. BSUHM 60, 61, 75–78.

Xerocomaceae

Phylloporus rhodoxanthus (Schweinitz : Fries) Bresadola#; Synonyms: *Paxillus rhodoxanthus* (Schweinitz) Ricken, *Phylloporus pelletieri* (Léveillé) Quélet. Common names: Gilled Bolete, Goldgills. Delaware County. BSUHM 52.

(CANTHARELLALES)

Cantharellaceae

Cantharellus cibarius Fries#. Common names: Chanterelle, Yellow Chanterelle, Golden Chanterelle, Girolle, Pfifferling. Delaware County. BSUHM 22, 70, 337.

Hydnaceae

Climacodon septentrionale (Fries) Karsten; Synonyms: *Steccherinum septentrionale* Fries, *Hydnum*

septentrionale Fries. Common name: Northern Tooth. Delaware County. BSUHM 417.

(CORTINARIALES)

Cortinariaceae

Gymnopilus liquiritae (Persoon) Karsten. Delaware County. BSUHM 418.

Simocybe centunculus (Fries) Karsten; Synonyms: *Naucoria centuncula* (Fries) Gillet, *Ramicola centunculus* (Fries) Watling. Common name: American Simocybe. Delaware County. BSUHM 419.

Crepidotaceae

Crepidotus crocophyllus (Berkeley) Saccardo. Delaware County. BSUHM 420.

(DACRYMYCETALES)

Dacrymycetaceae

Calocera cornea (Batsch : Fries) Fries*; Synonym: *Calocera palmata*, (Schumacher : Fries) Fries. Common names: Small Staghorn, Yellow Staghorn Fungus, Club-like Tuning Fork, Yellow False Coral. Delaware County. BSUHM 421.

(GANODERMATALES)

Ganodermataceae

Ganoderma applanatum (Persoon) Patouillard*; Synonyms: *Ganoderma lipsiense* (Batsch) Atkinson, *Fomes applanatus* (Persoon) Gillet, *Polyporus applanatus* (Persoon) Wallroth. Common names: Artist's Conk, Artist's Fungus, Designer's Mushroom. Delaware County. BSUHM 422.

Ganoderma lucidum (Curtis : Fries) Karsten*. Common names: Ling-zhi, Reishi, Ling-chih, Mannentake. Delaware County. BSUHM 423.

(HERICIALES)

Clavicoronaceae

Clavicorona pyxidata (Persoon : Fries) Doty; Synonym: *Artomyces pyxidatus* (Persoon) Jülich. Common names: Crown Coral Fungus, Crown Coral Mushroom, Crown-tipped Coral Fungus. Grant County and Henry County. BSUHM 424, 425.

Hericiaceae

Hericium coralloides (Scopoli : Fries) S.F. Gray*; Synonym: *Hericium ramosum* (Bulliard) Letellier. Common name: Comb Tooth. Delaware County and Henry County. BSUHM 426, 427.

Lentinellaceae

Lentinellus cochleatus (Persoon : Fries) Karsten; Synonym: *Lentinus cochleatus* Persoon. Common names: Aniseed Cockleshell, Cockleshell Fungus, Cockleshell Lentinus. Henry County. BSUHM 428.

Lentinellus ursinus (Fries) Kühner*; Synonym: *Lentinus ursinus* Fries. Common name: Bear Lentinus. Delaware County. BSUHM 429.

(HYMENOCHAETALES)

Hymenochaetaceae

Inonotus dryadeus (Persoon : Fries) Murrill; Synonym: *Polyporus dryadeus* Persoon : Fries. Common names: Warted Oak Polypore, Oak Bracket. Delaware County. BSUHM 430.

Inonotus glomeratus, (Peck) Murrill; Synonym: *Polyporus glomeratus* Peck. Common name: Green-pored Bracket. Grant County. BSUHM 431.

Phellinus gilvis (Schweinitz) Patouillard*; Synonym: *Polyporus gilvis* (Schweinitz) Fries. Common names: Mustard-yellow Polypore, Oak Conk. Delaware County. BSUHM 432.

(LYCOPERDALES)

Geastraceae

Geastrum saccatum Fries*. Common names: Earthstar, Nested Earthstar, Sessile Earthstar, Rounded Earthstar. Delaware County and Grant County. BSUHM 433, 480.

Lycoperdaceae

Calvatia gigantea (Batsch : Persoon) Lloyd*; Synonyms: *Lycoperdon giganteum* Batsch : Persoon, *Langermannia gigantea* (Batsch : Persoon) Rostkovius, *Bovista gigantea* (Batsch : Persoon) Nees, *Calvatia maxima* Schaeffer. Common name: Giant Puffball. Delaware County. BSUHM 111, 112.

Lycoperdon perlatum Persoon*; Synonym: *Lycoperdon gemmatum* Batsch. Common names: Puffball, Devil's Snuffbox, Pearly Puffball, Warted Puffball, Gem-studded Puffball, Common Puffball. Delaware County. BSUHM 114.

(NIDULARIALES)

Nidulariaceae

Crucibulum laeve (Hudson) Kambly; Synonym: *Crucibulum vulgare* Tulasne & C. Tulasne. Common names: Common Bird's Nest Fungus, White Bird's Nest, White-egg Bird's Nest. Grant County. BSUHM 434.

Cyathus stercoreus (Schweinitz) De Toni. Common names: Dung Loving Bird's Nest Fungus, Bird's Nest Fungus. Delaware County. BSUHM 435.

(PORIALES)

Coriolaceae

Abortiporus biennis (Bulliard : Fries) Singer; Synonyms: *Polyporus biennis* (Bulliard : Fries) Fries, *Polyporus abortivus* Peck, *Daedalea biennis* Bulliard : Fries, *Heteroporus biennis* (Bulliard : Fries) Lázaro. Common name: Blushing Rosette. Delaware County. BSUHM 436.

Bjerkandera adusta (Willdenow : Fries) Karsten; Synonyms: *Polyporus adustus* (Willdenow) Fries, *Gloeoporus adustus* (Willdenow : Fries) Pilát.

Common names: Gray-pored mushroom, Smoky Polypore, Smoky Bracket. Delaware County. BSUHM 437.

Cerrena unicolor (Bulliard : Fries) Murrill*; Synonyms: *Trametes unicolor* (Bulliard) Pilát, *Daedalea unicolor* Bulliard : Fries. Common name: Mossy Maze Polypore. Delaware County. BSUHM 438.

Daedaleopsis confragosa (Bolton : Fries) Schroeter; Synonyms: *Daedalea confragosa* (Bolton : Fries) Fries, *Trametes rubescens* (Albertini & Schweinitz) Fries. Common names: Thin-maze Flat Polypore, Thin-walled Maze Polypore, Blushing Bracket. Henry County. BSUHM 439.

Daedalea quercina Fries. Common names: Maze-gill Fungus, Oak Maze-gill, Thick-maze Oak Polypore. Delaware County. BSUHM 440.

Grifola frondosa (Dickson : Fries) S.F. Gray; Synonym: *Polyporus frondosus* (Dickson) Fries. Common names: Maitake, Hen of the Woods, Sheep's Head. Delaware County. BSUHM 441.

Hapalopilus nidulans (Persoon : Fries) Karsten; Synonyms: *Polyporus nidulans* Fries, *Polyporus rutilans* (Fries) Karsten. Common names: Tender Nesting Polypore, Cinnamon Bracket. Delaware County. BSUHM 442.

Laetiporus cincinnatus (Morgan) Burdsall, Banik & Volk; Synonyms: *Laetiporus sulphureus* var. *semialbinus* Peck, *Polyporus sulfureus* var. *semialbinus* Peck. Common name: White-pored Chicken of the Woods. Delaware County. BSUHM 443.

Laetiporus sulphureus (Bulliard : Fries) Murrill var. *sulphureus*; Synonyms: *Laetiporus sulphureus* (Bulliard : Fries) Murrill, *Polyporus sulphureus* (Bulliard : Fries) Fries. Common names: Sulphur Polypore, Sulphur Shelf, Chicken of the Woods, Chicken Mushroom, Rooster Comb. Delaware County. BSUHM 444.

Perenniporia ohiensis (Berkeley) Ryvarden; Synonym: *Trametes ohiensis* Berkeley. Delaware County and Grant County. BSUHM 445, 446.

Trametes conchifer (Schweinitz : Fries) Pilát; Synonyms: *Poronidulus conchifer* (Schweinitz) Murrill, *Polyporus conchifer* (Schweinitz) Fries. Common name: Little Nest Polypore. Delaware County and Henry County. BSUHM 447, 448.

Trametes versicolor (Linnaeus : Fries) Pilát*; Synonyms: *Coriolus versicolor* (Linnaeus : Fries) Quélet, *Polyporus versicolor* (Linnaeus) Fries. Common names: Turkey Tails, Multicolored Polypore, Many-zoned Polypore, Kawaratake, Yun-zhi. Delaware County. BSUHM 449.

Tyromyces fumidiceps Atkinson. Delaware County. BSUHM 450.

Lentinaceae

Phyllotopsis nidulans (Persoon : Fries) Singer*; Synonyms: *Pleurotus nidulans* (Persoon) Kummer, *Claudopus nidulans* Persoon. Common name: Orange Mock Oyster. Delaware County. BSUHM 451.

Pleurotus pulmonarius (Fries) Quélet. Delaware County. BSUHM 452.

Polyporaceae

Polyporus alveolaris (De Candolle : Fries) Bondartsev & Singer; Synonyms: *Polyporus mori* (Pollini : Fries) Fries, *Favolus alveolaris* (De Candolle : Fries) Quélet. Common name: Hexagonal-pored Polypore. Henry County. BSUHM 453.

Polyporus arcularius (Batsch) Fries. Common names: Spring Polypore, Fringed Polypore. Delaware County. BSUHM 454.

Polyporus badius (Persoon) Schweinitz*; Synonym: *Polyporus picipes* Fries. Common names: Bay-colored Polypore, Black-footed Polypore. Delaware, Grant, and Henry counties. BSUHM 455, 456, 457.

Polyporus elegans Bulliard : Fries*; Synonym: *Polyporus varius* (Persoon) Fries (by some mycologists). Common names: Elegant Polypore, Black-footed Polypore. Delaware County and Grant County. BSUHM 458, 459.

Polyporus squamosus (Hudson : Fries) Fries*. Common names: Dryad's Saddle, Pheasant's-back Polypore. Delaware County. BSUHM 460.

(RUSSULALES)

Russulaceae

Lactarius piperatus (Fries) S.F. Gray#; Synonym: *Lactarius pergamenus* (Swartz) Fries. Common names: Peppery Lactarius, Peppery Milkcap, Peppery Milky, Peppery White Milkcap. Delaware County. BSUHM 42.

Lactarius psammicola f. *glaber* Hesler & Smith#. Delaware County. BSUHM 79–81.

Lactarius volemus (Fries) Fries var. *volemus*#. Common names: Tawny Milkcap Mushroom, Weeping Milkcap, Chichitake, Voluminous-latex Milky, Bradley, Tawny Lactarius, Apicot Milkcap. Delaware County. BSUHM 74.

Russula albida Peck. Delaware County. BSUHM 461.

Russula brevipes Peck; Synonym: *Russula delica* Fries. Common names: Short-stalked White Russula, Short-stemmed Russula. Henry County. BSUHM 462.

Russula fragilis (Persoon) Fries. Common names: Fragile Red Russula, Fragile Russula. Delaware County. BSUHM 463.

(SCHIZOPHYLLALES)

Schizophyllaceae

Schizophyllum commune Fries*. Common name: Common Split Gill. Delaware County and Henry County. BSUHM 464, 465.

(SCLERODERMATALES)

Sclerodermataceae

Scleroderma areolatum Ehrenberg; Synonym: *Scleroderma lycoperdoides* Schweinitz. Common name: Common Earthball. Delaware County. BSUHM 466.

Scleroderma cepa (Vaillant) Persoon; Synonym: *Scleroderma flavidum* Ellis & Everhart. Common names: Earthball, Stone Fungus, Onion-shaped Scleroderma, Smooth Earthball. Delaware County. BSUHM 467.

(STEREALES)

Meruliaceae

Gloeoporus dichrous (Fries : Fries) Bresadola*; Synonyms: *Caloporus dichrous* (Fries) Ryvarden, *Polyporus dichrous* Fries. Common name: Gelatinous-pored Polypore. Delaware County. BSUHM 468.

Steccherinaceae

Irpex lacteus (Fries : Fries) Fries*; Synonym: *Polyporus tulipiferus* (Schweinitz) Overholts. Common name: Milk-white Toothed Polypore. Delaware County. BSUHM 469.

Steccherinum ochraceum (Persoon : Fries) S.F. Gray. Common name: Ochre Spreading Tooth. Delaware County. BSUHM 470.

Stereaceae

Stereum complicatum (Fries) Fries; Synonym: *Stereum rameale* (Schweinitz) Burt. Common names: Crowded Parchment, Parchment Fungus. Delaware County. BSUHM 471.

Stereum ostrea (Blume & Nees : Fries) Fries; Synonyms: *Stereum fasciatum* Schweinitz, *Stereum lobatum* Fries. Common name: False Turkey-tail. Delaware County and Henry County. BSUHM 472, 473.

(TREMELLALES)

Exidiaceae

Ductifera pululahuana (Patouillard) Wells; Synonym: *Exidia alba* (Lloyd) Burt. Common name: Pale Jelly Roll. Delaware County. BSUHM 474.

(MITOSPORIC FUNGI)

Pleurocolla compressa (Ellis & Everhart) Diehl; Synonym: *Dendrodochium compressum* Ellis & Everhart. Delaware County. BSUHM 475.

PHYLUM MYXOMYCOTA

(LICEALES)

Lycogalaceae

Lycogala epidendrum (Linnaeus) Fries#. Common names: Wolf's Udder, Wolf's Milk Slime Mold, Wolf's Milk Slime, Toothpaste Slime. Delaware County. BSUHM 146, 147, 334.

Trichiaceae

Hemitrichia clavata (Persoon) Rostafinski#. Common names: Club-Shaped Slime Mold. Yellow-fuzzy Cone Slime. Delaware County. BSUHM 168.

Trichia flavoginea (Batsch) Persoon#. Delaware County. BSUHM 170.

(PROTOSTELIALES)

Ceratiomyxaceae

Ceratiomyxa fructiculosa (Müller) Macbride. Common name: Coral Slime. Grant County. BSUHM 481.

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Manuscript received 3 December 2003, revised 7 September 2004.

2004. Proceedings of the Indiana Academy of Science 113(2):109–114

CHANGES IN POPULATION STRUCTURE OF YELLOW PERCH FOLLOWING MANUAL REMOVAL

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ABSTRACT. In small inland lakes that support stunted yellow perch *Perca flavescens*, reduction of fish density by manual removal may be the only feasible approach to increase growth and alter population structure. We examined changes in the size distribution, condition, and stock density of yellow perch in Soldier Lake, Michigan between pre-manipulation (1997 and 1998) and post-manipulation years (1999 and 2000). Although mean total length of yellow perch decreased from 95.4 to 85.2 mm between pre- and post-manipulation years, there was a 12% increase in larger (> 150 mm) fish in the population following manual removal. The yellow perch population following manual removal was broader in total length and was positively kurtotic and skewed toward larger fish than in pre-manipulation years. The mean weight of yellow perch (9.6 g) prior to manual removal was significantly lower (13.8 g) than for fish collected during post-manipulation years. Mean relative weight (92 and 85, respectively) and proportional stock density (38 and 5, respectively) of yellow perch were higher in post-manipulation years than prior to the manual removal. Based on these study results, we recommend the use of manual removal to increase the growth and size structure of yellow perch in small inland lakes.

Keywords: Yellow perch, *Perca flavescens*, manual removal, growth, size structure

Many small lakes and impoundments in north temperate latitudes support abundant populations of yellow perch (*Perca flavescens*) that are too small to sustain a viable recreational fishery (Persson 1983; Sandheinrich & Hubert 1984; Jansen & MacKay 1991). Limited growth and subsequent stunting of overabundant yellow perch can occur from intra- or interspecific competition for limited trophic resources (Ridgway & Chapleau 1994). For example, Lott et al. (1996) found that the lack of an adequate prey base during their ontogenetic shifts in yellow perch food habits from zooplankton to aquatic insects was a major factor that contributed to the slow growth. This problem is often compounded because this species may reach reproductive maturity at small sizes and young ages (i.e., within the first year of life), which allows for rapid production of offspring that often cannot be harvested by sport fishes or anglers (Herman et al. 1959; Diana & Salz 1990; Roff 1992). As a result, yellow perch are unable to grow to lengths where they can consume piscine prey and reach harvestable sizes.

To alleviate stunting of fish populations in small lakes, a variety of management solutions have been proposed including the alteration of trophic resources and introducing or augmenting top predator populations (Noble 1980; Diana 1987). However, management solutions based solely on density-dependent mechanisms have been met with mixed success because predator stocking rates are either inadequate to control prey fishes or are too high and result in resource competition with other desirable sport fish populations (Diana 1987; Wydoski & Wiley 1999). In addition, maintaining an adequate and effective preda-

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tor base is often difficult in many small lakes due to excessive recreational harvest. However, the use of entrapment gears to reduce densities of overabundant fishes has been shown to be effective for meeting management objectives. For example, the manual removal of black crappie (*Pomoxis nigromaculatus*) and black bullhead (*Ameiurus melas*) from a Wisconsin lake had a significant impact on population size structure of these fishes, increasing the density of black crappie longer than 200 mm in length by 430% and the number of black bullhead longer than 260 mm in length by 1100% (Hanson et al. 1983).

Soldier Lake, a small lake located in the Upper Peninsula of Michigan, supports a stunted yellow perch population. Because top piscivores in this system have been unable to effectively control the yellow perch population, we examined the effectiveness of using fyke nets to manually remove yellow perch. This study compared changes in the size distribution, condition, and population structure of yellow perch between pre-manipulation (1997 and 1998) and post-manipulation years (1999 and 2000).

METHODS

Study area.—Soldier Lake (Chippewa County, Michigan) is a shallow (mean depth = 4.4 m) lake with a surface area of 7.6 ha (Fig. 1). Although the pH of the lake is moderately acidic (range 4.5–6.9), dissolved-oxygen levels are sufficient to support aquatic life (range 7.4–10.8 mg/L). The lake supports sparse emergent and submergent aquatic macrophytes around its perimeter, and the bottom substrate is comprised of a thick layer of detritus. A small recreational fishery for yellow perch and largemouth bass (*Micropterus salmoides*) exists. The latter species was stocked at low levels as fingerlings in 1996 and 1997 by the Michigan Department of Natural Resources. The only other fish species present in the lake is the brown bullhead (*Ameiurus nebulosus*) which occurs at a relatively low density. The invertebrate community is dominated by odonates, but also includes trichopterans, ephemeropterans, coleopterans, dipterans, hemipterans, and gastropods.

Data collection.—Yellow perch were collected from Soldier Lake using four fyke nets from 1997 through 2000. Pre-manipulation (i.e., prior to manual removal) years were

Figure 1.—Map of the Upper Peninsula of Michigan showing the location (●) of Soldier Lake in Chippewa County.

1997 and 1998, while post-manipulation (i.e., following manual removal) years included data collected in 1999 and 2000. Two of the fyke nets had a 2.0 m × 1.2 m mouth and were covered by 1.3 cm stretch mesh, while the other two fyke nets had a 1.0 m × 0.7 m mouth and were covered by 0.6 cm stretch mesh. Fyke nets were set overnight at four fixed stations once each month during April and October 1997, 1998, and 1999 and once each month from May through September 2000.

In 1997, 1998, Fall 1999, and 2000, yellow perch were measured for total length (TL) to the nearest 1 mm, weighed to the nearest 0.01 g, and released alive at the location of capture. In April 1999, fish were measured and weighed as previously described and permanently removed from Soldier Lake (approximately 8116 fish weighing a total of 642 kg). Condition of yellow perch was calculated using relative weight (W_r), described as:

$$W_r = (W/W_s) \times 100$$

where W was the measured wet weight of each individual fish and W_s was the length-specific standard weight for yellow perch derived from the standard-weight equation $\log_{10}(W_s) = -5.386 + 3.23 \times \log_{10}TL - 5.386$ (Wege & Anderson 1978; Willis et al. 1991; Anderson & Neumann 1996). Proportional stock-density (PSD) was calculated using length-category values developed by Gabelhouse (1984), where the minimum total length for each category was as follows: stock (130 mm) and quality (200 mm). Relative stock density indices were not calculated because of the low numbers of yellow perch collected that were greater than quality length (i.e., the minimum length for yellow perch [200 mm] that anglers like to catch; Gabelhouse 1984).

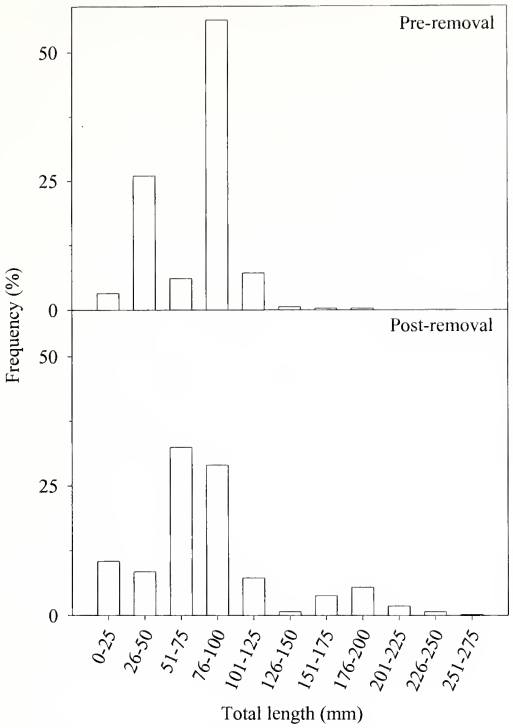

Figure 2.—Length-frequency distributions of yellow perch in Soldier Lake, Michigan, during pre-manual removal (1997 and 1998) and post-manual removal (1999 and 2000) years. Fish were grouped into 25 mm total length intervals.

Yellow perch captured in fyke nets during 2000 (n = 401) received a partial dorsal fin clip prior to release back into the lake for a mark-and-recapture population estimate using the Chapman's modification of the Schnabel estimator (Schnabel 1938; Chapman 1951). For the population abundance estimate, we determined a 95% confidence interval using a Poisson distribution (Ricker 1975). Biomass of yellow perch (kg/ha) was estimated to compare Soldier Lake to other inland lakes by multiplying the overall mean weight by the estimated population abundance and dividing it by the total surface area of the lake.

Data analyses.—For all statistical analyses, pre-manipulation (i.e., 1997 and 1998) and post-manipulation (1999 and 2000) year data were pooled to incorporate annual variability and increase sample sizes and statistical power. Total length, wet weight, and relative weight of yellow perch were compared between pre- and post-manipulation years using student's t-tests that were Bonferroni corrected to control experiment-wise error (Zar 1999). In addition, qualitative comparisons of proportional stock density index values for yellow perch were also made between pre- and post-manipulation years. Estimates of kurtosis and skewness were used to further describe changes in length-frequency distributions between pre- and post-manipulation years, and a Kolmogorov-Smirnov test was used to test the significance of the skewness estimates (Zar 1999). All data analyses were conducted using the SAS statistical analysis program (SAS Institute 1990) at an $\alpha = 0.05$ level of confidence.

RESULTS

Prior to the manual removal, small (< 150 mm TL) yellow perch were abundant in Soldier Lake, comprising 99% of the population (Fig. 2). Within one year following the manual removal, the mean total length was significantly lower, decreasing by 10 mm. However, the number of yellow perch greater than 150 mm TL increased by 12% (Fig. 2). Following the manual removal, the length-frequency distribution was more broadly distributed, positively kurtotic, and skewed toward larger size classes than in pre-manipulation years (Table 1).

The mean weight of yellow perch was significantly greater following the manual removal (13.8 g; range 0.6–166.0 g) than during pre-manipulation years (mean = 9.6 g; range 1.0–88.0 g; Table 1). Following the manual removal, Soldier Lake contained approximately 79,000 yellow perch (95% confidence interval; 30,905–152,052 fish), with an estimated biomass of 124 kg/ha (95% confidence interval; 52.5–258.5 kg/ha). Relative weight and proportional stock density index values of yellow perch were greater in post-removal years (92 and 38, respectively) than for pre-manipulation years (85 and 5, respectively; Table 1).

DISCUSSION

Our results suggest that the manual removal of yellow perch from Soldier Lake was effective in altering the size structure and condition while also improving the quality of the recreational fishery. One year following the manual removal, the population structure of yellow perch had shifted to larger (> 150 mm)

Table 1.—Comparison of mean (ranges in parentheses) total length (mm), wet weight (g), relative weight, proportional stock density (PSD), skewness, and kurtosis of yellow perch collected from Soldier Lake, Michigan, before (1997 and 1998) and after (1999 and 2000) conducting a manual removal in spring 1999. Contrast denotes t and D statistic, respectively.

Response variable	Pre-manipulation	Post-manipulation	Contrast	P-value
Total length (mm)	95 (25–240)	85 (41–252)	5.5	<0.01
Wet weight (g)	9.6 (1.0–88.0)	13.8 (0.6–166.0)	5.2	<0.01
Relative weight	85 (37–361)	92 (41–132)	−2.8	<0.01
Proportional stock density	5	38	—	—
Kurtosis	−0.12	2.26	—	—
Skewness	−0.08	1.71	0.45	<0.01

fish with a greater relative weight. Post-manipulation biomass of yellow perch in Soldier Lake (124 kg/ha) was substantially greater than average biomass estimates reported in small lakes in Wisconsin (56 kg/ha), Michigan (32 kg/ha), and Minnesota (21 kg/ha; Herman et al. 1959). A significant change in stock structure also occurred after the manipulation, with proportional stock density index estimates increasing more than seven-fold in post-removal years. According to Anderson & Weithman (1978), a balanced yellow perch population has a proportional stock density that ranges between 30 and 60. A post-manipulation proportional stock density of 38 suggests the population may be developing into a more balanced state. Our results also suggest that this shift in population structure and increase in relative weight may be the result of lower intraspecific competition for food resources. We hypothesize that Soldier Lake would continue to benefit from future manual removals of yellow perch, which may continue to increase the size structure and condition of this sport fish population.

The increase in relative weight that was observed in Soldier Lake following the manual removal indicates that yellow perch were in better condition than prior to the manipulation. An increased weight gain in yellow perch has the potential to impact individual fitness (Keast & Eadie 1985; Ludsin & DeVries 1997; Sammons et al. 1999). As a result, aggressive and successive manual removals may be required to maintain continued positive increases in growth. Because weight is strongly correlated with fecundity in yellow perch, the effects of a reduction in the adult population in Soldier Lake may be only measurable over a single season. In subsequent years, large year classes could return the population to its pre-manipulation abundance and biomass levels as suggested by the strong year class that we observed the year following the manual removal in Soldier Lake (W. Bauer unpubl. data). Similar results have also been observed by Amundsen et al. (1993) for Arctic char (*Salvelinus alpinus*) in Norway. Additional examinations will be required to determine whether the differences in size structure that we observed continue or revert to pre-manipulation conditions due to multiple strong year classes.

Lack of the appropriate size and type of prey available for yellow perch has been shown to limit growth and cause stunting in other systems (Wootton 1990; Hayes et al. 1992). In Soldier Lake, we determined that the diet of yellow perch was comprised primarily of macroinvertebrates, with few yellow perch consuming piscine prey (W. Bauer unpubl. data). Lott et al. (1996) found that yellow perch maintained rapid growth on diets that were dominated by large macroinvertebrate prey. However, odonates were the most common macroinvertebrate by number and weight in the diet of yellow perch in Soldier Lake. If fish are available as prey, the diet of yellow perch will typically shift from macroinvertebrates to fish when yellow perch reach between 150–200 mm in length (Clady 1974). In Soldier Lake, yellow perch rarely reach lengths that allow them to consume piscine prey. Further, piscine prey were not readily available as forage in this system (W. Bauer unpubl. data). Therefore, stunting of yellow perch in Soldier Lake appears to result from intraspecific competition for limited resources, particularly for fish prey within predator ingestibility limits.

Manual removal was chosen over other types of population-manipulation approaches due to the ease of implementation and cost effectiveness. In contrast, the large-scale stocking of predators (in this case, largemouth bass) would have been costly and most likely met with little success (Diana 1987; Wydoski & Wiley 1999). Maintaining a predator base that is effective at reducing high densities of yellow perch may be difficult in small impoundments due to high angling pressure and a lack of suitable habitat (Olson et al. 2001). Increased recruitment as a response to decreased fish density from manual removal does suggest that the fish population could return to a stunted condition following cessation of this manipulation (Amundsen et al. 1993). For this reason, we recommend that additional manual removals should be implemented in subsequent years as it has been reported that at least two consecutive years are required for lasting affects (C. Bassett, USDA Forest Service - Hiawatha National Forest, pers. commun.). As a result, we predict that the size structure and condition of yellow perch will continue to increase due to the reduction in population abundance and intraspecific competition for trophic resources in Soldier Lake. In addition, the production of strong year classes should provide large yellow perch with a piscine prey base. Piscine prey, as an important component in growth for yellow perch, will enable the population to maintain larger sizes and move toward a more balanced size structure. Therefore, we recommend manual removals as a management tool for alleviating slow growth of yellow perch populations in small inland lakes and impoundments.

ACKNOWLEDGMENTS

We thank the USDA Forest Service and Michigan Department of Natural Resources for their collaboration during this project. We also thank the Lake Superior State University Fish and Wildlife Club, the Soo Area Sportsman's Club, and K. Pangle and K. Kruckeberg for their assistance in data collection. Constructive comments on an earlier draft by S. Scott, C. Bassett, J. Reattoir, M. Siepker, D. Daugherty, A. Kennedy and A. Benson improved this manuscript.

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Manuscript received 8 March 2004, revised 9 August 2004.

2004. Proceedings of the Indiana Academy of Science 113(2):115–122

INCIPIENT SECOND DORSAL FIN EGG MIMICS IN THE SPOTTAIL DARTER, *ETHEOSTOMA SQUAMICEPS?*

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ABSTRACT. In five of the 10 species in the spottail darter species group, breeding males develop white or yellow knobs on the second dorsal fin. In those species with more well-developed knobs, female spawning decisions may be influenced by these knobs, which are presumed to be egg mimics. In the spottail darter (*Etheostoma squamiceps*), the knobs are small and club-shaped and may represent an early stage of evolutionary development. We tested the hypothesis that female choice drives knob evolutionary development by looking for evidence that male spottail darters with larger or more obvious knobs had larger broods or shorter pre-spawning intervals. Males with more well-developed knobs (as judged from photographs reviewed by human observers) were not guarding larger broods than males with less well-developed knobs. Similarly, knob size (measured from photographs as height above the fin margin) did not correlate with brood size. Finally, during a two day interval, males guarding eggs did not have significantly larger knobs than males without eggs. These results suggest that female choice is weak or absent in early stages of knob evolutionary development, and that another mechanism such as genetic drift or an alternate function for knobs may be necessary to produce the larger knobs found in other species.

Keywords: *Catonotus*, dorsal fin knob, breeding tubercle, female choice, behavior

In many fish species in which the male defends the nest site, a female is more likely to spawn with a male that already has eggs in his nest (for example, see Ridley & Rechten 1981; Marconato & Bisazza 1986; Unger & Sargent 1988; Knapp & Sargent 1989; Sikkel 1989; Kraak & Groothius 1994; and Goulet 1998). This finding has prompted several studies that attempt to identify the strategies males use to increase reproductive success. One of the strategies thus far revealed is egg mimicry (Knapp & Sargent 1989; Bart & Page 1991; Porter et al. 2002).

Darters of the subgenus *Catonotus* practice egg clustering in which males defend a nest cavity where females deposit eggs in a monolayer on the ceiling (Page 1985). In several species in this group, breeding males develop enlargements on the distal spines or rays of the first or second dorsal fins (Page & Swofford 1984). These structures, ranging from small, white club-like enlargements to larger, orange fleshy knobs, are hypothesized to be egg mimics that increase the chance that a female will spawn with a nest-guarding male (Page & Bart 1989; Bart & Page 1991). Subsequent studies have shown that such structures may influence female spawning decisions. For example, Knapp & Sargent (1989) showed that female fantail darters (*Etheostoma flabellare*) prefer to spawn with males with intact fleshy knobs and trailing orange ocelli on the first dorsal fin compared to males from which the knobs and ocelli had been removed. In a similar experiment, Strange (2001) tested female preference for males in three species of the spottail darter species group (*Etheostoma oophylax*, *E. pseudovulatum*, and *E. neopterum*) with well-developed knobs. Females preferred males with intact knobs over conspecific males with the knobs removed. Purported egg mimics are not limited to the dorsal fins, as Porter et al. (2002) have shown a positive correlation between the

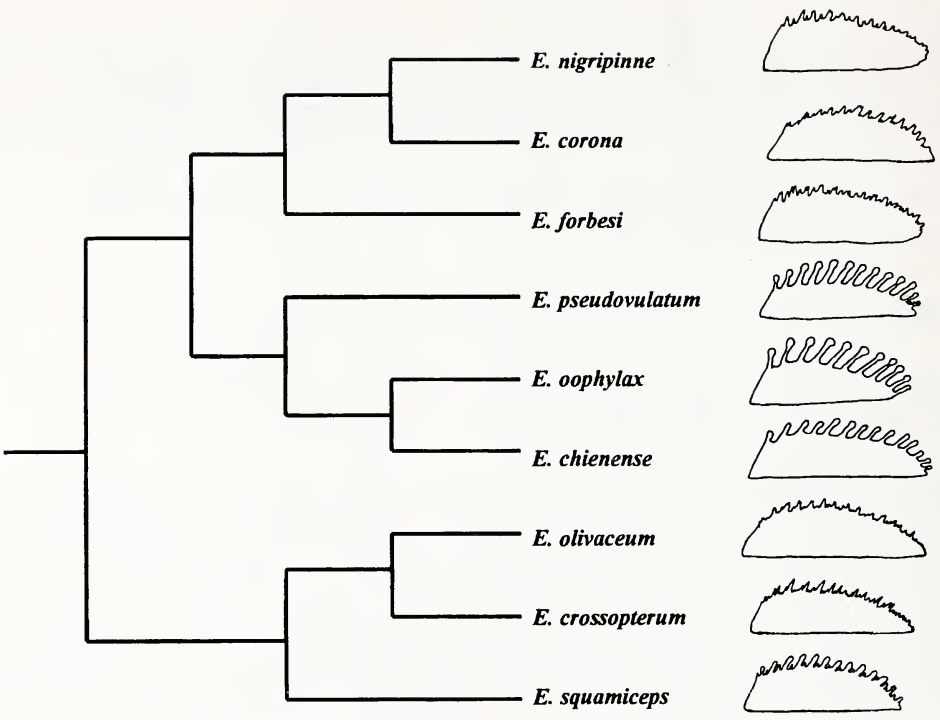

Figure 1.—Phylogenetic affinities of members of the spottail darter species group based on Porterfield et al. 1999. Drawings show a lateral view of the second dorsal fin of breeding males (based on drawings in Page et al. 1992). The phylogenetic status of *Etheostoma neopterum* (not shown), a species with large knobs similar to *Etheostoma oophylax*, is currently unresolved.

number of white spots (presumed egg mimics) on the pectoral fins of male striped darters (*Etheostoma virgatum*) and the estimated minimum number of female spawning partners.

Fleshy knobs occur to varying degrees on the second dorsal fin in breeding males in five of 10 species in the spottail darter species group (*Etheostoma oophylax*, *E. chienense*, *E. neopterum*, *E. pseudovulatum*, and *E. squamiceps*; Page et al. 1992). A phylogenetic analysis of darters in the subgenus *Catonotus* using both morphological and molecular characters suggests these knobs may have evolved more than once. White or yellow second dorsal fin knobs occur in a clade comprising the guardian darter (*E. oophylax*), the relict darter (*E. chienense*), and the egg-mimic darter (*E. pseudovulatum*; Porterfield et al. 1999; Fig. 1). The lollypop darter (*E. neopterum*), which also has relatively large yellow knobs on the second dorsal fin, may belong to the above clade (Page et al. 1992); however, cytochrome *b* data place it in a clade with species lacking knobs (Porterfield et al. 1999), which if true would represent a separate evolution of these knobs. The spottail darter (*E. squamiceps*) is most closely related to *E. olivaceum* and *E. crossopterum*, two species lacking enlargements of the second dorsal fin (Fig. 1). The small, white club-like enlargements of the distal rays of the second dorsal fin in *E. squamiceps* (Fig. 2) may therefore be an incipient second (or third depending on the status of *E. neopterum*) independent development of a second dorsal fin egg mimic in this species group.

In order for an egg mimic to be an effective signal, the mimic must be both conspicuous and generally similar to actual eggs. The initial appearance of a dorsal fin knob may be due to pleiotropy, since fleshy white "breeding tubercles" associated with spines and rays of pectoral, pelvic, or anal fins of breeding males are common in darters (Bart & Page 1991). These structures do not seem to function directly in nest cleaning (Bart & Page 1991), although they may decrease damage to eggs due to contact with spines. Their evolu-

Figure 2.—Breeding male spottail darter with well-developed, club-like knobs on the second dorsal fin. The darter was collected in a tributary of the Bayou Creek drainage in southwestern Indiana. The standard length of the fish is 68 mm.

tionary elaboration as egg mimics would theoretically begin when they are detected by females and elicit an increased tendency to spawn, but at what point does this happen? If females are biased toward any structure resembling eggs, then even small, white club-like enlargements such as those found in *E. squamiceps* may elicit a response from females. Alternatively, incipient knobs may need to reach a (1) minimum size and/or (2) appropriate color (eggs in *Etheostoma* are typically orange; Page 1983) before females respond. If this is the case, then factors other than female choice may be necessary to maintain and enlarge the initial fin ray breeding tubercle.

We examined the possibility that knob size influences female choice by looking at knob development and reproductive success (indicated by brood size) in male spottail darters (*Etheostoma squamiceps*). Compared to knobs in other species in this group, those in *E. squamiceps* males are small and club-shaped (Figs. 1, 2), and possibly at an early stage of evolutionary development. Egg mimics may enhance male reproductive success in two ways: first, they may signal the presence of eggs when in fact the male has not yet spawned, reducing the pre-spawning interval in males with more well-developed knobs. Second, they may increase the apparent number of eggs a male is defending, such that males with larger knobs may attract more females, increasing brood size. We examined both of these possibilities using spottail darters in southwestern Indiana. *Etheostoma squamiceps* is a state-endangered species in Indiana (Indiana Department of Natural Resources 1993), which precluded studies involving the removal or modification of existing knobs on males. Therefore, we used direct measurements of knobs, measurements of knobs from photographs, and human observer evaluation of knob development from photographs of males captured while guarding nests, and compared knob development with reproductive success (brood size).

This study rests on a critical assumption—that most or all of the males were guarding eggs that they had sired. Alloparental care, in which males guard eggs they did not sire (Unger & Sargent 1988), has thus far been doc-

umented in two species of darters—the tesselated darter (*Etheostoma olmstedi*) and the striped darter (*E. virgatum*). Constantz (1985) observed that male tesselated darters frequently moved between nest sites (rocks), with larger males displacing smaller males from limited breeding sites and abandoning them when most of the available surfaces for egg deposition were filled. These abandoned nests were then frequently occupied by smaller males that tended the eggs and attempted to attract additional females. Alloparental care in the striped darter was documented by genetic analysis of guarding males and eggs; however, the extent of alloparental care varied, as some foster eggs were found in four of eight nests in one population but only in one of 11 nests in another (Porter et al. 2002).

Alloparental care probably occurs opportunistically in most species in the subgenus *Catonotus* as males compete for limited nest sites. In a laboratory experiment, Bandoli (2002) found that male *E. squamiceps* given their original nest sites and eggs spent significantly more time defending them and consumed fewer eggs than did males given a foreign nest site with foster eggs, a distinction expected if alloparental care occurs in the field. However, in a field study, Bandoli (1997) found limited movement of breeding males between nest sites. Nine of 14 uniquely-marked *E. squamiceps* males in southern Indiana were consistently found at the same nest sites for several weeks. Three of these males defended multiple consecutive broods without changing nest sites (Bandoli 1997). Further, there was no evidence that any of the five males that changed nest sites abandoned eggs or inherited foster eggs (Bandoli unpubl. data).

We believe that while alloparental care probably occurs in *E. squamiceps*, the available evidence suggests that it occurs too infrequently to invalidate the assumption that the number of eggs in a nest can be used as an indicator of the fitness of the guarding male.

METHODS

All spottail darters used in this study were collected in tributaries of the Black River (Posey County, Indiana) or Bayou Creek (Vanderburgh County, Indiana). Males were collected by placing artificial nest sites (sections of ceramic field tiles; Bandoli et al. 1991) in streams in late March. During the subsequent two-month breeding season, males guarding tiles were easily captured by hand net. All fish were handled in the field, marked with a small caudal fin clip, and released at their places of capture. Standard lengths (SL) were measured to the nearest mm, and any broods found were photographed so that eggs could be counted from projected slides.

The relation between knob size and reproductive success (number of eggs guarded) was examined in three ways. The first two involved the use of photographs taken of 35 males captured in April and May of 1998 and 1999. All males were guarding nests with eggs at the time they were captured and photographed. Males that had been captured previously (indicated by the clipped caudal fin) were excluded. Males were photographed in a 23 cm × 16 cm × 6.5 cm glass aquarium. We used a black 17 × 21 cm acrylic plastic sheet (Plexiglas®) as a background and to force the male against the front of the aquarium. At least two photographs (ISO 400 slides using natural light) were taken of each male with the camera positioned so that the entire male was visible and filled the frame. We asked 29 human observers to assess the overall appearance of the knobs by having them rate knob development from projected slides of the male spottail darters. The degree of knob development varies among breeding male *E. squamiceps* in Indiana (pers. observ.), ranging from well-developed and obvious (as shown in Fig. 1-F in Page et al. 1992) to poorly-developed and more similar to *E. crossopterum* (Fig. 1-E in Page et al. 1992). To prepare the observers for the task of assessing variation in the second dorsal fin, we provided copies of the drawings of second dorsal fins of *E. squamiceps* and *E. crossopterum* taken from Page et al. 1992. Observers were first shown all of the slides without scoring. They were then asked to view the slides again and to rate knob appearance as most similar to *E. crossopterum* (score of 0 – no obvious swelling of distal tips of rays), most similar to *E. squamiceps* (score of 2 – club-like knobs present as distinct swellings of distal rays) or intermediate (score of 1). Slides were shown in random order, and 10 of the darters had one additional slide placed randomly in the tray to test for consistency of ratings. Only ratings from observers

who gave the same scores on both the first and second photo of the same male at least 8 of 10 times were used in this analysis (n = 10). Mean knob development scores between 1.5–2 were categorized as strongly developed; means between 0.5–1.4 were intermediate, and those from 0–0.4 were labeled weakly developed. The relation between knob development and reproductive success was assessed by comparing the mean number of eggs guarded by males in each category.

We used the same slides described above to measure knob height. We measured SL and the height above the fin margin of the second, third and fourth full knobs on the second dorsal fin to the nearest mm on projected slides of each male. Only males that had at least one slide in which the fish was positioned such that SL and at least two of the three knobs could be accurately measured were included. We also attempted to measure anterior-posterior knob width, but found the precision to be too low to be reliable. For each male, the ratio between actual SL measured in the field and the SL measured from the projected slide was used to convert mean projected knob height to actual size. Since body size may influence mate choice in *E. squamiceps* (Bandoli 1997), we used partial correlation to control for standard length and compare mean actual knob height to brood size.

Finally, to investigate the possibility that the primary value of knobs is as egg mimics that increase the probability that a female will spawn with a male with an empty nest, we captured an additional 25 nest-guarding males in a 100 m stretch of a tributary of the Black River on 13–14 April 2001. Seventeen of the males were guarding eggs, while the remaining eight males guarded empty nest sites. Using the largest intact knob (usually the 4th), knob height above the fin margin and anterior-posterior knob width at the widest point were measured to the nearest 0.1 mm in the field using a stereoscope fitted with an ocular micrometer. Measurements were made while males were briefly anesthetized using MS 222® (ethyl 2-aminobenzoate, methanesulfonic acid salt); all males were allowed to fully recover before being returned to their nests. To compensate for the possibility that larger males may have larger knobs, relative knob height and width were determined by dividing knob height and width by SL. We used t-tests to compare (1) mean knob height and knob width and (2) mean relative knob height and width between males with and without eggs.

RESULTS

The 13 males captured in 1998 were not significantly different in either SL (t = 0.08; P = 0.93) or brood size (t = 1.75; P = 0.09) from the 22 males captured in 1999. Data from both years were therefore combined. The mean SL of the 35 photographed males was 74.2 mm (range 62–85 mm); brood size ranged from 95–1754 eggs ($\bar{x}$ = 786.9).

Only five of the males were judged by human observers to have well-developed knobs on the second dorsal fin (mean score $\geq$ 1.5); 14 were judged as poorly developed (mean score $\leq$ 0.4). Males with well-developed knobs guarded an average of 593 eggs; males with poorly-developed knobs guarded an average of 755.8 eggs. To improve sample sizes, males were divided into two categories—those with mean knob scores $>$ 1.0 (mean score = 1.39; n = 14) and those with mean scores $<$ 1.0 (mean score 0.38; n = 21). Males with more well-developed knobs guarded an average of 772.5 eggs; those with less well-developed knobs guarded an average of 796.5 eggs. The difference was not significant (t = 0.16; P = 0.88). Therefore, males with more well-developed knobs as judged by human observers were not guarding more eggs. Interestingly, males judged to have more well-developed knobs were significantly smaller (mean SL = 71.6 mm) than males with less well-developed knobs (mean SL = 76.0; t = 4.4; P = 0.02).

For 22 of the 35 males photographed, there was at least one slide on which both SL and knob height above the fin margin could be accurately measured. Most of those excluded were due to either the tip of the nose being obscured by the corner of the aquarium or lateral flexion of the tail preventing an accurate measure of SL. Mean actual knob height was 2.1 mm (range 1.1–3.2 mm); this was not significantly different from the mean of 2.02 mm for 25 breeding males measured directly in the field in 2001 (see below; t = 0.57; P = 0.57). Mean actual knob height correlated weakly but significantly with SL (Spearman rank correlation, r_s = 0.43; P = 0.047), indicating that knob size increases with body size. Partial correlation analysis controlling for SL found

no relation between knob height and brood size ($r = 0.18$; $P = 0.44$).

The 25 males guarding nests on 13–14 April 2001, ranged from 52–71 mm in SL ($\bar{x} = 61.4$ mm). The mean knob height above the fin margin was 2.02 mm (range = 1–3 mm); knob width ranged from 0.3–1 mm ($\bar{x} = 0.65$ mm). Males that were guarding eggs had a mean knob height of 2.09 mm, which was not significantly different from that of males guarding empty nests (1.88 mm; $t = 1.13$; $P = 0.13$). Knob width was also not significantly different (0.64 and 0.68 mm, respectively; $t = 0.09$; $P = 0.46$). Relative knob height was not significantly different (0.034 and 0.031 for males with and without eggs, respectively; $t = 1.20$; $P = 0.12$). Similarly, relative knob width (0.010 for males guarding eggs, 0.011 for males without eggs) was also not significantly different ($t = 0.70$; $P = 0.25$). Knob height had a significant positive correlation with SL ($r = 0.40$; $P = 0.05$); knob width also correlated positively but non-significantly with SL ($r = 0.38$; $P = 0.059$). There were no significant correlations between SL and either relative knob height ($r = 0.08$; $P = 0.72$) or relative knob width ($r = 0.01$; $P = 0.99$), indicating that knob size increases proportionately with male size.

DISCUSSION

The results of this study do not support the hypothesis that the size of the second dorsal fin knobs in *E. squamiceps* males influences spawning decisions by females. There is indirect evidence that female spottail darters prefer to spawn with males already defending eggs (Bandoli 2002); however, the results of this study provide no evidence that males with taller or larger knobs have a shorter prespawning period, which is predicted if these knobs function as egg mimics. There were no significant correlations between brood size and knob size, implying that females choosing among males already defending eggs are not influenced by the presence of larger knobs. Finally, males with knobs rated by human observers as well-developed did not have larger broods than males with knobs rated as poorly-developed.

It may be argued that there is insufficient variation in the small knobs in *E. squamiceps* to allow females to discriminate. In *E. oophylax*, a species with well-developed knobs and similar to *E. squamiceps* in SL, the maximum anterior-posterior diameter of mimics of 35 males collected in Ledbetter Creek in April 1999 ranged from 0.8–1.8 mm (Page & Knouft 2000), which is greater than the range of variation in knob widths measured in this study (0.3–1.0 mm). However, knob height above the fin margin in this study ranged from 1–3 mm, which is a greater range of variation than in anterior-posterior knob diameter in *E. oophylax* and may be more important as a potential signal. In *E. oophylax*, knobs and the fin rays that support them have a "lollypop" appearance, and the knobs alone may constitute the presumed egg mimic, with the rays functioning only to elevate the knobs. In contrast, knobs in *E. squamiceps* are club-shaped (see Fig. 1), such that there is no distinct "beginning" to the knob as the ray projects above the fin margin. Hence, if knobs in *E. squamiceps* are functioning as a signal, the entire structure above the fin margin may be important.

Knob height correlated weakly but significantly with male size in both the 1998–1999 sample and the 2001 sample, suggesting that the effect of knob size may be difficult to separate from body size, which influences reproductive success in *E. squamiceps* (Bandoli 1997). However, the fact that males rated by human observers as having more well-developed knobs were significantly smaller in SL suggests that, despite larger males having slightly larger knobs, they may be more conspicuous in smaller males.

The results of this study do not support the hypothesis that female choice is the initial force driving the evolutionary enlargement of second dorsal fin breeding knobs in spottail darters. However, there are several factors that may have obscured the predicted relationship between knob size and reproductive success. It is possible that the observed lack of response by females to variation in male knob size may be a local effect, and that female *E. squamiceps* in Illinois or Kentucky may be more discriminating. It is also possible that there may be more variation in knob size (and therefore more discrimination) in this species in other locations; geographic variation in knob size has been demonstrated in *E. oophylax* (Page & Knouft 2000). Environmental factors such as turbidity and photic conditions may decrease female sensitivity to subtle cues.

Additionally, variation in nest site availability and the resulting male competition (Bandoli 1997) may also influence female choice, temporally or geographically masking their use of other cues. Finally, any relation between knob size and reproductive success would be masked if males with larger knobs had higher rates of filial cannibalism, or if the frequency of alloparental care is substantially higher than we assume.

This study uses indirect evidence of female choice of males based on knob development, and it can be argued that a more direct approach, such as a knob-removal study (e.g., Strange 2001) may be more appropriate. However, even if females do prefer males with small knobs over males lacking them, it still would not explain their evolutionary elaboration into larger, more egg-like structures unless females also preferred males with more well-developed knobs over males with smaller knobs. To date, no study has examined the relationship between knob size and fitness in any of the strongly-knobed species in the spottail darter species group. Moreover, Strange's (2001) study looked at the three species of *Catonotus* with yellow knobs. It is possible that knobs don't function as egg mimics until they develop a color similar to the orange typical of darter eggs. This could be tested by looking at female choice in *E. chienense*, which has distinct but relatively small white knobs.

Presumed egg mimics influence female spawning decisions in several species in the *Catonotus* subgenus; however, the results of this study imply that female choice may not drive the initial enlargement of male second dorsal fin knobs. This suggests that other factors, such as genetic drift, or an as yet unidentified function for small enlargements of dorsal fin rays may be involved.

ACKNOWLEDGMENTS

Field work was conducted under permits 1703 (1998), 1858 (1999) and 2245 (2001) issued by the Indiana Department of Natural Resources and under recommendations of the 1988 ASIH Guidelines for Use of Fishes in Field Research. We thank G. Bryant for field help, and R. Strange, S. Beeching, and an anonymous reviewer for helpful comments on previous drafts of the manuscript. The University of Southern Indiana provided logistical support.

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Manuscript received 7 January 2004, revised 12 March 2004.

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DESCRIPTION OF DEVELOPMENTAL STAGES OF THE STONECAT, *NOTURUS FLAVUS* AND THE SLENDER MADTOM, *NOTURUS EXILIS* (SILURIFORMES: ICTALURIDAE)

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ABSTRACT. The stonecat, *Noturus flavus*, and the slender madtom, *N. exilis*, deposit clumps of adhesive eggs on firm substrates beneath slab rocks. In both species, eggs are spherical, demersal, possess a narrow perivitelline space, and are held together by an adhesive gelatinous substance. Diameters of stonecat eggs range from 3.4–3.8 mm, while the slender madtom eggs range from 3.2–3.6 mm. Eggs differ in yolk color. Stonecat egg yolk is yellow, and yolk from the slender madtom varies from amber to orange. Slender madtom eggs incubated at 25 °C hatched in 8–9 days (187–210 hr). Stonecats hatch as 7.2–7.5 mm larvae, while slender madtom hatch at 5.5–6.3 mm total length (TL). Larval stonecats possess 18–24 preanal myomeres and 24–29 postanal myomeres. Slender madtoms have 17–26 preanal myomeres and 21–29 postanal myomeres. Newly-hatched larvae of both species do not possess cutaneous melanophores; however, slender madtom had a uniform subcutaneous pigmentation pattern that gave the body an overall light brown color. Pigmentation of yolk sac larvae consists of scattered melanophores over the dorsum in slender madtom, while stonecat are unpigmented except for the retinae. Yolk sacs were absorbed in some stonecats by 12.3 mm, and most were completely absorbed by 13.0 mm TL. Slender madtom yolk sacs were absorbed between 12.6 and 13 mm TL. In stonecats the adult diagnostic character of an overhanging jaw is apparent by 11.3 mm TL.

Keywords: Development, *Noturus*, *Schilbeodes*, early life history

The stonecat, *Noturus flavus*, is one of the widest-ranging madtoms, occurring throughout the upper and mid-Mississippi River basin, south to Tennessee and Arkansas, much of the St. Lawrence–Great Lakes basin, the Hudson Bay (Red River) drainage, and the Hudson River drainage, New York (Taylor 1969; Burr & Warren 1986; Page & Burr 1991). The slender madtom, *Noturus exilis*, has a smaller and overlapping range with two centers of distribution. It occurs in the Tennessee, Cumberland, and Green river drainages from northern Alabama to central Kentucky, and in the upper Mississippi River basin from southern Wisconsin and southern Minnesota to the Ozark and Ouchita highlands of Arkansas, Kansas, and Missouri (Taylor 1969; Page & Burr 1991). Neither Taylor (1969) nor Grady & LeGrande (1992) considered the two species to be close relatives; however, their superficial similarity often makes identification difficult in areas of sympatry.

Walsh & Burr (1985) and Mayden & Burr (1981) report on many aspects of the biology of *N. flavus* and *N. exilis*, including reproduction and early life history. Additional life history information is provided by Greeley (1929), Gilbert (1953), Carlson (1966), and Becker (1983) for *N. flavus*. Taylor (1969), Burr & Mayden (1984), Vives (1986), and Etnier & Starnes (1994) provide additional life history information for *N. exilis*. Except for information on egg incubation, general larval development, and illustrations of various larval or juvenile stages (e.g., Mayden & Burr 1981; Burr & Mayden 1984; Walsh & Burr 1985), no meristic or morphometric data is available for either species. Herein we provide details of meristic, morphometric, and pigmentation characters with the goal of determining diagnostic characters necessary for separating sympatric species of *Noturus*.

METHODS

Laboratory-raised series of egg, larval, and early juvenile stonecat and slender madtom were examined. Stonecat eggs were field-collected from nests and from laboratory-spawned fish from the Meramec River, Missouri. Stonecat ovaries were dissected from adults collected from the Kankakee River, LaPorte County, Indiana. Slender madtom eggs were collected from nests in Green Creek and Hutchins Creek, Union County, Illinois. Specimens were reared in small culture containers, and representative series were preserved in 10% formalin. Culture water was Carbondale, Illinois, tap water that was carbon filtered and conditioned to remove chloramines. Water quality included neutral pH and temperatures ranging from 22–24 °C. Partial water changes were made daily to reduce increases in ammonia from food and waste.

Ontogenetic series, comprised of six eggs and 34 larvae and early juvenile slender madtoms and 23 eggs and 32 larvae and early juvenile stonecats, were studied for changes in 31 morphometric and 13 meristic characters. Preanal myomeres included all body segments from the head to an imaginary vertical line at the posterior anus (including those bisected by the line), while postanal myomeres included those posterior to the vertical line plus an urostyle segment (Snyder 1979). All lengths are reported as total length (TL) unless otherwise noted. Vertebral counts were made from specimens cleared and stained using the techniques described by Fritzsche & Johnson (1980). Minor modifications were made to the method used at the Mississippi River Fisheries Center (L.E. Holland-Bartels pers. commun.). Figures were drawn following Sumida et al. (1984).

The following length, depth, and width measurements were made: horizontal length from anterior margin of snout to anterior margin of eye (snout length), to dorsal finfold/spinous dorsal fin (D origin), to origin of adipose fin (adipose origin), to posterior margin of vent (preanal length), and to posterior margin of hypural plate or notochord (standard length), maximum horizontal length of yolk sac (yolk sac length). Fin lengths (P1 and P2) were measured along the plane of the fin from the origin to the most distal margin. Body depths were measured vertically from the dorsal to ventral margins and included the yolk sac but not the fins or finfolds. The vertical depths were measured immediately behind the posterior margin of the eye (head depth), at origin of pectoral fin (shoulder depth), behind the posterior vent (preanal depth), and mid-postanal myomere (mean countable whole myomere myosepta between anus and penultimate myomere: mid-postanal depth), at penultimate myosepta (caudal peduncle depth), and maximum yolk sac depth (includes only yolk: yolk sac depth). Body width was measured immediately posterior to the eye (head width).

RESULTS

Stonecat
Noturus flavus Rafinesque

Eggs.—Preserved vitellogenic oocytes removed from specimens from the Kankakee River, LaPorte County, Indiana, were amber and ranged in diameter from 1.9–3.4 mm (n = 23, $\bar{x}$ = 3.0 mm). Mature eggs are yellow, demersal, spherical, and adhesive. Eggs contain a translucent yolk, a compound oil globule ($\bar{x}$ = 1.18 mm), a smooth, unpigmented chorion, and a narrow perivitelline space (0.1 mm). Stonecat eggs used for the larval series were field collected from beneath slab rocks; thus, the age of the eggs was unknown.

Larvae.—*Morphology:* Morphometrics of stonecat larvae and early juveniles are reported in Table 1. The following lengths describe the initial onset of select structure development. At 7.2–7.6 mm (newly hatched): mandibular and mental barbels present as buds, weakly developed jaw and pectoral fins, yolk sac spherical and pale yellow, with a distinct vitelline vein network and a single cluster of composite oil globules, head deflected slightly over the yolk sac, and eyes oval. Notochord flexion occurs by 8.2 mm, nasal barbels present as buds by 8.5 mm, caudal fin rays form by 8.6 mm, anal fin rays by 9.8 mm, and the soft dorsal rays and anterior spine by 9.8 mm. Pelvic fin buds form by 9.8 mm and first pelvic fin rays form by 10.9 mm. Ten incipient pectoral fin rays form by 9.6 mm, and first rays form in pectoral fins by 12.3 mm. Dorsal origin situated over preanal myomere 5, adipose fin origin over preanal myomere 13 (9.4–11.9 mm). Gut straight, caudal fin truncate (9.4 mm). Principal rays of median fins seg-

mented by 10.8–11.4 mm. Infraorbital and lateral head canals form by 9.7 mm, completely formed by 11.3 mm. Lateral line begins to form at 9.9 mm. Upper jaw overhangs lower jaw by 11.3 mm. Yolk absorbed between 12.3–13.0 mm. Supraorbital, supratemporal, and preoperculomandibular head canals form and infraorbital completely form by 12.9 mm. Incipient dorsal and anal finfolds partially differentiated by 9.6 mm, completely differentiated by 19.2 mm. No pectoral spine serrae develop on anterior or posterior margins.

Meristics: Preanal myomeres 18 (3), 19 (5), 20 (9), 21 (9), 22 (5), or 24 (1) (n = 32, $\bar{x}$ = 20.4), postanal myomeres 24 (1), 25 (4), 26 (9), 27 (7), 28 (9), 29 (2) (n = 32, $\bar{x}$ = 26.8), with 44 to 50 total myomeres. Total vertebrae 37–40 (n = 3, $\bar{x}$ = 38.5), including one urostylar element. Fin ray counts and length at appearance are presented in Table 2.

Pigmentation: Newly-hatched larvae (7.2–7.5 mm), body without dermal pigment, yolk yellow, and eyes pigmented. At 8.0–8.6 mm, cutaneous melanophores concentrated on cephalic region and nape (Figs. 1, 2). At 9.4–10.6 mm, scattered cutaneous melanophores cover dorsal and dorso-lateral surface with concentrations of melanophores on the cephalic region and posterior to the eye. The body has scattered cutaneous melanophores that outline epaxial myosepta of each myomere. No pigmentation on the ventral half of the body, barbels, or finfolds (Fig. 3). Between 10.7–11.3 mm, scattered cutaneous melanophores outline the eye and the epaxial myosepta, and postanal hypaxial myosepta are pigmented from the anus to the caudal peduncle (Fig. 4). At lengths from 12.3–22.5 mm (late larvae and early juveniles), pigmentation pattern continues as described but increases in density and concentration between the myosepta; barbels, fins, and the ventral surface anterior of the vent remain without any pigmentation (Fig. 5).

Slender Madtom
Noturus exilis Nelson

Eggs.—Vitellogenic oocytes removed from specimens from Mill Creek, Missouri, are orange and range in diameter from 1.5–3.4 mm (n = 12, $\bar{x}$ = 2.9 mm). Mature eggs are amber, demersal, spherical, and adhesive. Eggs contain a translucent yolk, a composite oil globule ($\bar{x}$ = 1.18 mm), a smooth and unpigmented chorion, and a narrow perivitelline space (0.1 mm). Slender madtom eggs were spawned and incubated under laboratory conditions. Eggs hatch in 187–210 h at 25 °C.

Larvae.—*Morphology:* Morphometrics of slender madtom larvae and early juveniles are reported in Table 3. The length at initial formation of select structures is summarized. At 5.5–6.5 mm (newly hatched): mandibular and mental barbels present as buds, weakly-developed jaw and pectoral fins, yolk sac spherical, yolk sac amber to orange, with a single cluster of composite oil globules, a distinct vitelline vein network, head deflected slightly over yolk sac, and eyes spherical. Incipient fin rays form in dorsal fin by 6.7 mm, notochord flexion and caudal fin rays, anal fin rays, soft dorsal rays and anterior dorsal spine form simultaneously by 8.2 mm, and pectoral fin rays form by 8.8 mm. Nasal barbel buds developed by 7.5 mm. Upper and lower jaws of equal length (11.3 mm). Pelvic fin buds and first pelvic fin rays form by 11.7 mm. Yolk absorbed between 12.6–13.0 mm, dorsal and anal finfolds partially differentiate by 12.2 mm, completely differentiated by 18.8 mm. Dorsal origin situated over preanal myomeres 4–5, adipose fin origin over preanal myomere 12–16 (6.7–14.2 mm). Gut straight, caudal fin truncate (12.0 mm). Principal rays of median fins segmented between 10.9–11.5 mm. Infraorbital and lateral head canals form between 9.1–10.9 mm, completely formed by 11.5 mm. Lateral line began to form at 11.9 mm. Supraorbital, supratemporal, and preoperculomandibular head canals begin to form and infraorbital completely forms between 11.5-13.5 mm. Differentiation of pectoral spine posterior serrae apparent by 19.0 mm.

Meristics: Preanal myomeres 17 (1), 18 (3), 19 (20), 20 (8), 24 (1), or 26 (1) (n = 34, $\bar{x}$ = 19.4), postanal myomeres 21 (1), 24 (11), 25 (3), 26 (10), 27 (3), 28 (5), or 29 (1) (n = 34, $\bar{x}$ = 25.6), with 42–49 total myomeres. Total vertebrae 36–39 (n = 3, $\bar{x}$ = 38.1), including one urostylar element. Fin ray counts and length at appearance presented in Table 2.

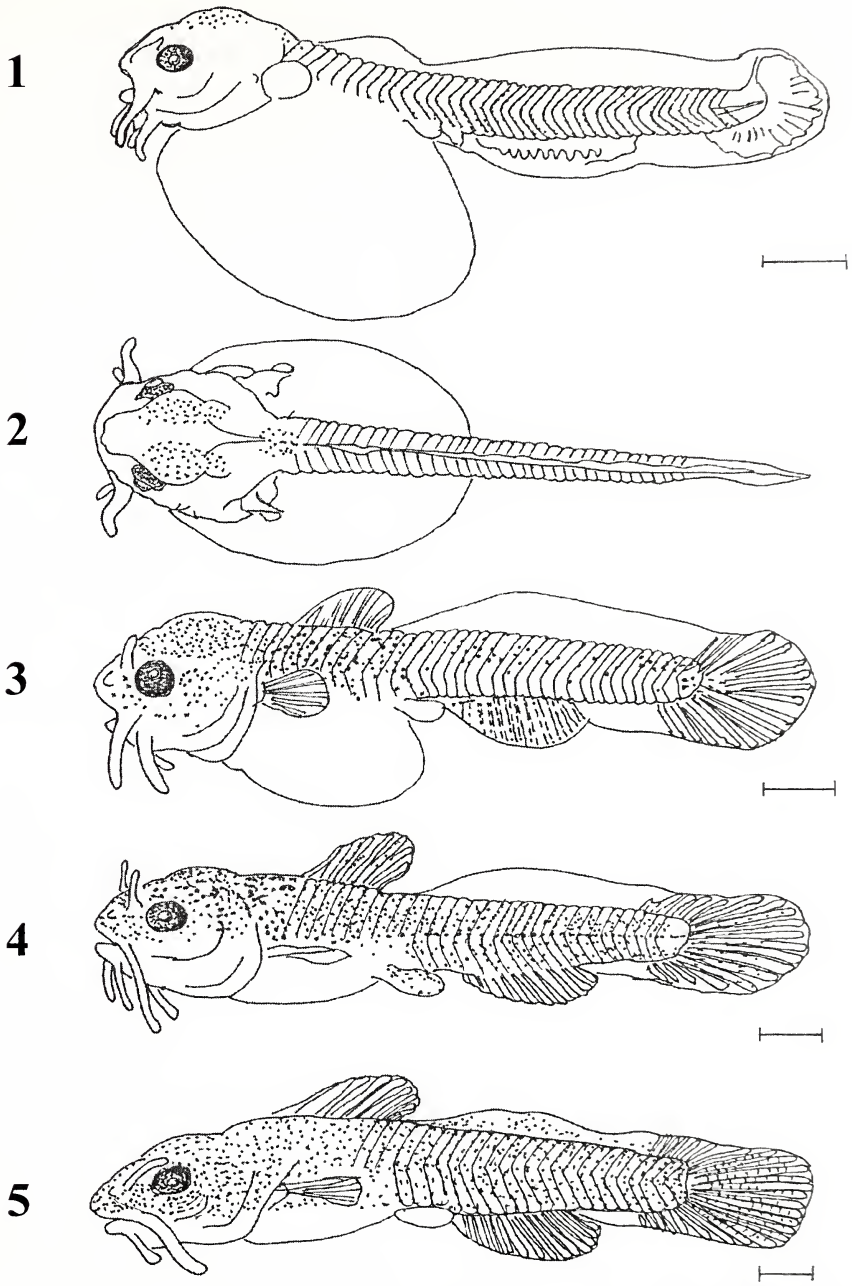
Pigmentation: Newly-hatched larvae (5.5–8.0 mm), eyes pigmented, yolk amber to orange, dermal pigment absent; however, a subdermal pigmentation gives body a brown appearance. No pigmentation is present in either the barbel or finfolds (Figs. 6, 7). Between 8.8–11.7 mm, cutaneous melanophores

Table 1.—Morphometry of *Noturus flavus* and early juveniles grouped by select intervals of total length (n = sample size). Characters expressed as mean of percent head* and total length with a single standard deviation.

	Total length (TL) intervals (mm)					
Measure	7.6–8.6 (n = 3)	9.4–11.9 (n = 19)	12.3–14.0 (n = 4)	14.2–14.6 (n = 3)	19.2 (n = 1)	21.9–22.5 (n = 2)
Length, % TL						
Standard	91.3 ± 0.7	85.6 ± 1.9	82.0 ± 1.3	82.8 ± 0.8	82.0	84.6 ± 3.3
Snout*	23.9 ± 11.6	30.2 ± 4.3	30.9 ± 2.7	30.0 ± 0.1	29.9	31.1 ± 3.1
Eye*	23.4 ± 1.2	19.2 ± 3.9	19.2 ± 1.5	18.0 ± 0.2	17.6	18.3 ± 1.4
Head	23.6 ± 0.4	23.4 ± 1.6	25.2 ± 3.5	28.4 ± 0.3	25.1	24.0 ± 0.9
Dorsal origin	28.0 ± 0.2	27.8 ± 1.5	28.6 ± 2.3	28.7 ± 0.3	30.8	32.0 ± 1.4
Preanal	49.0 ± 0.5	46.6 ± 1.6	46.7 ± 1.5	46.3 ± 0.4	49.7	48.2 ± 3.9
Adipose origin	41.2 ± 0.6	42.0 ± 1.9	42.7 ± 0.9	42.9 ± 0.4	49.5	47.0 ± 0.3
Yolk sac	36.8 ± 7.8	27.4 ± 5.7	17.3 ± 2.7			
Fin length, % TL						
Pectoral	7.3 ± 1.3	12.0 ± 1.5	14.4 ± 1.3	12.7 ± 0.1	17.1	13.7 ± 2.1
Pelvic	2.56 ± 0.0	4.4 ± 1.9	7.5 ± 1.2	6.6 ± 0.0	9.7	10.5 ± 1.0
Depth, % TL						
Head	22.0 ± 2.4	15.4 ± 2.4	16.6 ± 4.2	13.0 ± 0.4	16.2	13.7 ± 0.6
Shoulder	31.3 ± 3.0	23.6 ± 4.3	18.0 ± 2.7	15.0 ± 0.1	17.0	15.6 ± 1.1
Anus	9.1 ± 0.6	9.3 ± 1.0	9.6 ± 1.4	9.7 ± 0.0	9.9	10.6 ± 0.1
Mid-postanal	7.9 ± 0.4	7.7 ± 0.8	7.6 ± 0.6	7.9 ± 0.1	7.3	7.6 ± 0.9
Caudal peduncle	5.8 ± 0.2	6.7 ± 0.6	6.0 ± 1.2	6.5 ± 0.0	6.5	6.4 ± 0.6
Yolk sac	24.6 ± 3.0	17.4 ± 5.1	8.2 ± 0.3			
Width, % TL						
Head	81.9 ± 7.1	77.8 ± 10.0	79.1 ± 10.6	61.5 ± 0.4	77.2	71.3 ± 5.4

Table 2.—Comparative meristic counts of *Noturus flavus* and *N. exilis* larvae and early juveniles based on length at initial formation and completion of adult complement.

Character	*Noturus flavus*	*Noturus exilis*
Dorsal spine/rays	I/6	I/6–7
First formed	9.8/9.8	9.8/6.7
Adult complement	9.8/9.8	9.6/8.8
Pectoral spine/rays	I/9–11	I/8–10
First formed	9.6/9.6	9.6/8.8
Adult complement	12.3/12.3	9.6/8.8
Anal rays	15–19	17–20
First formed	9.7	8.2
Adult complement	9.8	10.9
Pelvic rays	8–9	8–10
First formed	10.9	11.7
Adult complement	10.9	11.7
Caudal rays (upper + lower half)	29–32 + 27–31	20–26 + 21–36
First formed	8.2	8.2
Adult complement	11.4	11.6
Myomere counts		
Predorsal	5	4–5
Preanal	18–24	17–26
Postanal	24–29	21–29
Total	42–49	44–50



Figures 1–5.—*Noturus flavus*, stonecat, laboratory raised from Meramec River, Missouri. Scale bar equals 1 mm. 1. Yolk sac larva, lateral view, 8.5 mm TL; 2. Dorsal view; 3. Late yolk sac larva, lateral view, 9.9 mm TL; 4. Early juvenile, lateral view, 11.3 TL; 5. Juvenile, lateral view, 13.5 mm TL.

are concentrated dorsally over the optic and olfactory lobes and extending anteriorly onto upper lip. A few melanophores outline epaxial myosepta 6–8 and concentrate along these preanal myomeres. The barbels, finfold, and hypaxial portions of the body were unpigmented. Subdermal melanophores continue to cover the entire body with the exception of the finfolds and barbels (Figs. 8, 9). From 11.9– 12.9 mm, cutaneous melanophores

Table 3.—Morphometry of *Noturus exilis* and early juveniles grouped by select intervals of total length (n = sample size). Characters expressed as mean of percent head* and total length with a single standard deviation.

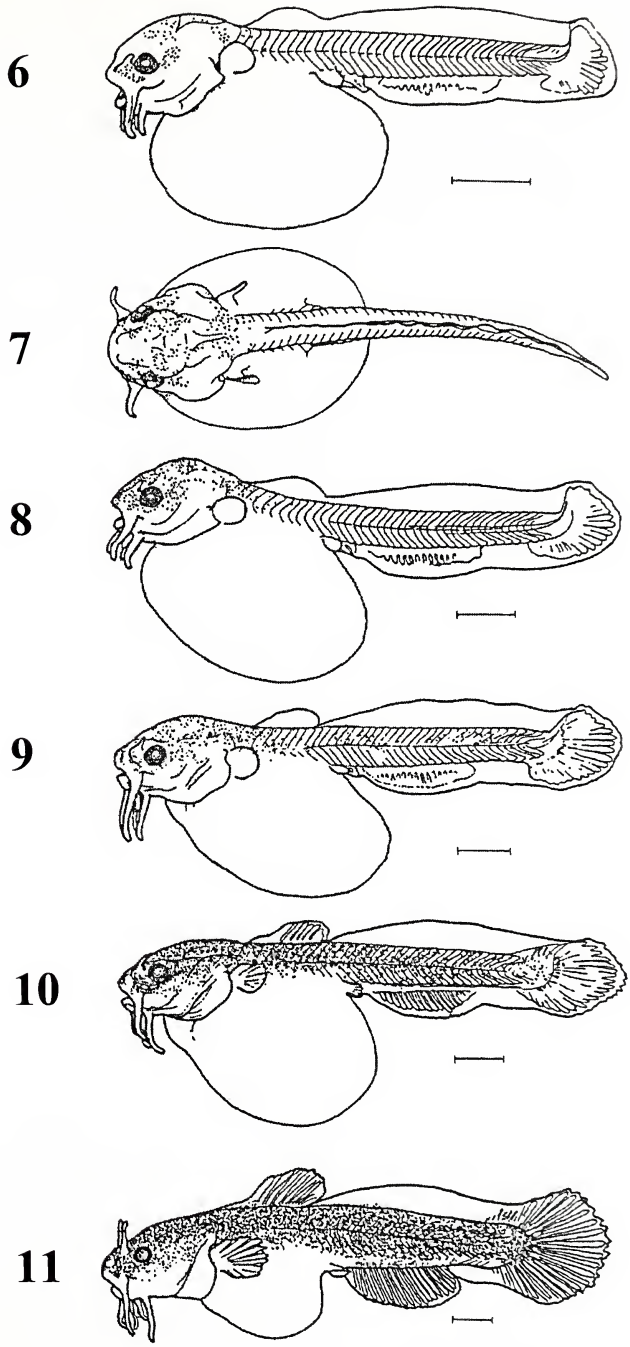
	Total length (TL) intervals (mm)					
Measure	6.7–9.6 (n = 9)	10.2–11.7 (n = 6)	12.0–13.7 (n = 10)	14.1–14.2 (n = 2)	19.0–23.6 (n = 3)	24.7–26.5 (n = 4)
Length, % TL						
Standard	89.1 ± 5.5	85.8 ± 3.2	83.7 ± 1.3	84.4 ± 0.4	74.7 ± 2.3	85.6 ± 1.0
Snout*	27.0 ± 5.5	28.9 ± 5.9	31.9 ± 2.5	26.3 ± 1.8	25.5 ± 0.8	30.2 ± 0.9
Eye*	19.1 ± 3.3	17.9 ± 1.8	16.8 ± 2.6	17.2 ± 1.6	13.3 ± 4.2	14.9 ± 2.2
Head	20.8 ± 3.3	23.6 ± 1.4	24.3 ± 2.4	22.8 ± 1.3	30.2 ± 3.2	21.8 ± 0.5
Dorsal origin	27.1 ± 2.7	28.8 ± 2.6	29.1 ± 2.2	28.9 ± 0.3	37.7 ± 2.2	29.4 ± 0.4
Preanal	48.5 ± 3.3	48.1 ± 1.2	47.7 ± 1.6	48.9 ± 3.3	51.6 ± 0.8	51.7 ± 0.6
Adipose origin	40.8 ± 2.5	45.0 ± 3.6	43.5 ± 2.5	41.9 ± 0.3	55.6 ± 0.7	44.5 ± 0.8
Yolk sac	42.7 ± 4.6	29.2 ± 4.4	25.6 ± 3.3			
Fin Length, % TL						
Pectoral	7.9 ± 2.2	11.8 ± 2.9	11.7 ± 1.7	13.1 ± 2.3	14.7 ± 1.2	11.9 ± 2.3
Pelvic	4.1 ± 1.5	4.9 ± 1.6	7.8 ± 1.9	7.1 ± 0.1	16.9 ± 4.4	11.9 ± 3.1
Depth, % TL						
Head	18.2 ± 6.4	15.5 ± 1.6	16.5 ± 1.9	16.6 ± 0.4	13.2 ± 0.2	11.7 ± 1.0
Shoulder	32.4 ± 5.2	26.7 ± 1.7	20.5 ± 3.2	20.0 ± 2.0	19.5 ± 1.2	15.4 ± 0.8
Anus	8.7 ± 1.3	10.6 ± 1.2	11.2 ± 1.2	11.7 ± 0.7	17.9 ± 0.2	12.7 ± 0.4
Mid-postanal	7.2 ± 1.1	8.1 ± 1.2	8.3 ± 1.0	8.3 ± 0.0	12.1 ± 0.6	10.1 ± 0.4
Caudal peduncle	5.5 ± 1.1	6.6 ± 0.9	6.1 ± 0.9	6.5 ± 0.4	11.1 ± 1.3	9.1 ± 0.9
Yolk sac	29.9 ± 8.1	23.1 ± 2.5	13.9 ± 7.4			
Width, % TL						
Head	86.6 ± 13.8	77.0 ± 7.4	74.7 ± 7.4	85.5 ± 0.6	76.8 ± 1.8	86.7 ± 5.4

cover the entire dorsum of the head and body exclusive of the fins. Punctate melanophores are distributed in the epaxial myosepta and over the myotomes. A secondary band of melanophores start at the snout and continues through the eye posteriorly to the origin of the dorsal fin. No melanophores occur on the fins or barbels. Subdermal pigmentation occurs over the entire body as in previous length intervals (Fig. 10). At 13.4–26.5 mm, juvenile pigmentation consists of discrete, punctate, cutaneous melanophores dorsally from the mandible to the caudal peduncle. The ventral portion of the body from the mandible to the vent is unpigmented, as well as the barbels, and median and paired fins. Subdermal pigmentation covers the remainder of the body (Fig. 11).

DISCUSSION

Development of the stonecat and slender madtom is similar to that of previously described *Noturus* (Burr & Mayden 1982; Dinkins 1984; Shute 1984; Starnes & Starnes 1985). At hatching, larvae are small (6.5–7.5 mm TL) and possess weakly-developed pectoral fins without incipient fin ray development until late in the yolk stage. Adult complements of fin rays develop prior to complete yolk absorption. The absorption of the large yolk sac causes the reduction of several depth measurements, including body depth/TL. Yolk sac larvae have a large, spherical yolk sac (yolk sac length/TL approximately 40%).

The description of *Noturus flavus* and *N. exilis* larvae increases the total number of *Noturus* with early life history morphometrics to six species. Additional species with some descriptive information include *N. miurus* (Burr & Mayden 1982), *N. flavipinnis* (Shute 1984), *N. baileyi* (Dinkins 1984), and *N. eleutherus* (Starnes & Starnes 1985). Described species of *Noturus* share similar body shape and overlapping numbers of preanal and postanal myomeres. The use of developmental characters will enable hypotheses of sister taxa relationships once additional compatible character sets are developed. The six species



Figures 6–11.—*Noturus exilis*, slender madtom, laboratory raised from Green Creek, Illinois. Scale bar equals 1 mm. 6. Newly-hatched yolk sac larva, lateral view, 6.5 mm TL; 7. Newly-hatched yolk sac larva, dorsal view; 8. Yolk sac larva, lateral view, 8.8 mm TL; 9. Yolk sac larva, lateral view, 10.6 mm TL; 10. Late yolk sac larva, lateral view, 11.9 mm TL; 11. Early juvenile, lateral view, 12.8 TL.

treated thus far exhibit subtle differences in the positioning and density of melanophores, myomere modes, and depth at select landmarks.

Adult characters, such as barbel length, position of the upper jaw, and pectoral spine development, are not adequate characters for separation of larval madtom development. Development of serrae on the anterior and posterior margins of pectoral fins are not reliable characters for separation of species until lengths are ≥ 19 mm TL. Length of the mandibular, mental, and nasal barbels change throughout larval development. The overhanging upper jaw is not a diagnostic trait until specimens reach minimum sizes of 11.3 mm TL; however, the slight differences at this size are difficult to distinguish. These characters are useless for identification of larval and juvenile specimens less than 24 mm TL.

Walsh and Burr (1985) found that stonecat egg diameters ranged from 3.5–4.0 mm, while eggs from the Kankakee River, LaPorte County, Indiana, ranged from 3.9–4.5 mm. Egg diameters of *N. exilis* ranged from 1.5–3.4 mm. Despite our reported egg diameters being slightly larger than those previously reported for *N. flavus* and slightly smaller than reported for *N. exilis*, we assumed that this was because ova were from different drainages and that different demes would have some intraspecific variation. The yolk coloration of *N. flavus* is yellow, while *N. exilis* is either amber or orange. The difference in yolk coloration between the two species is sufficient to distinguish them, since yolk color was similar between field-caught and laboratory-reared specimens. Yolk coloration is not considered to be affected by maternal diet nor yolk sac larval diet since it remains consistent during yolk sac stages and was similar between field and laboratory specimens.

No single character will distinguish larval stonecat and slender madtom; however, they can be diagnosed using a combination of pigmentation, myomere counts, and development of select structures relative to size. Adult *N. flavus* can be distinguished from all other *Noturus* species by the posterior extension of the premaxillary tooth patch. Larval slender madtom can be easily differentiated from stonecat since subdermal pigmentation gives the entire body an overall brown appearance. The stonecat does not possess subdermal pigmentation; however, extensive cutaneous melanophores occur dorsally over the body. At lengths greater than 9.4 mm TL, the stonecat has extensive dorsal melanophore pigmentation. Slender madtoms do not develop cutaneous melanophore pigmentation over the body until they reach at least 11.9 mm TL.

The stonecat and slender madtom differ in the modal number of preanal and postanal myomeres; however, the total number of preanal, postanal, and total myomeres overlaps. Modal number of myomeres for the stonecat is 20–21 preanal and 26–28 postanal. The slender madtom had a modal number of 19 preanal and 24–26 postanal myomeres.

Number of vertebrae is similar to values reported by Taylor (1969); however, we found 4–5 more postanal myomeres than vertebrae for the several specimens examined. Specimens examined for vertebral counts were juveniles, while Taylor examined adults. The discrepancies between vertebral number and number of myomeres are similar to that reported from Cyprinidae and Catostomidae (Snyder 1979). Snyder (1979) found that differences between number of vertebrae and myomeres vary by as much as six myomere elements for some taxa. In Synder's study, differences in myomere counts were attributed to technique differences in determining the most anterior and posterior myomeres. In our study, changes in vent position occur between larval and juvenile stages, as they do in Cyprinidae and Catostomidae. While vertebral numbers are within the expected range of values for preanal myomeres, values for postanal myomeres are higher than vertebral counts. In yolk sac and larval stages, there are greater numbers of postanal myomeres than postanal vertebrae. The difference in counts is attributed to the greater number of myomeres near the caudal peduncle and additional myomeres near the most anterior preanal myomere. Some variation between postanal myomere and vertebral counts can be due to a reduction in postanal myomere number during the formation of the hypural plate. The specimens we cleared and stained for our vertebral estimates were juveniles, while ranges in postanal myomere counts for each species were determined for yolk sac to early juvenile stages.

Madtoms exhibit developmental differences in select structures with increased growth. The slender madtom hatches at smaller sizes (5.5–

6.3 mm TL) than stonecats (7.2–7.5 mm TL). The slender madtoms develop dorsal, pectoral, and anal fin rays at smaller sizes than do stonecats, while pelvic fin rays form earlier in the stonecat. Complete yolk absorption occurs at approximately the same size in both species (12.3–13.0 mm TL for stonecat and 12.6–13.0 mm TL for slender madtom). Finfold absorption, lateral line, and cephalic canal formation occur at smaller sizes in the slender madtom than in the stonecat. Although none of these characters are diagnostic for either species, it is apparent that a combination of characters is adequate for separation. Although this is the first detailed description of these species and our material is based on limited geographic sampling, we suggest that identification of additional nesting populations will enable more detailed comparisons between these species.

ACKNOWLEDGMENTS

We appreciate the assistance of R. Mayden, K. Cummins, and S. Walsh who collected and reared specimens. Specimens from the Smithsonian Institute, United States Museum of Natural History (USNM) were provided by S. Jewett and R. Clayton. Illustrations were drawn by Beth Simon. Jim Berry provided review comments on a draft of the manuscript.

MATERIAL EXAMINED

Noturus flavus.—Southern Illinois University Collection (SIUC) uncatalogued. **MISSOURI:** *Franklin County:* Meramec River at State Park, 16 July 1981 (11); 16 July 1982 (10); 18 July 1982 (2); 20 July 1982 (2); 23 July 1982 (6). Large Rivers Research Collection (LRRC): **INDIANA:** *LaPorte County:* Kankakee River, at Kingsbury State Park, INBS 950 (1).

Noturus exilis.—Southern Illinois University Collection (SIUC) uncatalogued. **ILLINOIS:** *Union County:* Green Creek, 7.2 km W Anna and Illinois, Union County, Hutchins Creek; 4.8 km ENE Wolf Lake, 24 June 1982 (4); 29 June 1982 (2); 26 June 1982 (4); 20 June 1982 (1); 21 June 1982 (1); 21 June 1982 (1); 23 June 1982 (1); 24 June 1982 (1); 25 June 1982 (1); 26 June 1982 (1); 28 June 1982 (1); 2 July 1982 (5); 5 July 1982 (2); 7 June 1982 (4); 7 July 1982 (3); 18 August 1979 (1). U.S. National Museum: **TENNESSEE:** *Williamson County:* tributary of Harpeth River, E edge of Arrington, USNM 244958 (2).

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Manuscript received 2 January 2004, revised 4 August 2004.

2004. Proceedings of the Indiana Academy of Science 113(2):133–139

IMPLICATIONS OF CHINOOK SALMON PRESENCE ON WATER QUALITY STANDARDS IN A GREAT LAKES AREA OF CONCERN

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ABSTRACT. The Grand Calumet River watershed of southern Lake Michigan was surveyed to determine the occurrence of salmonid fishes during the predominant fall spawning run. Weekly core collections were performed at five core reaches and monthly synoptic collections at 14 additional reaches in the Grand Calumet River and Indiana Harbor Canal. Once temperatures were consistently below 19 °C, chinook salmon were present from mid-October until late November 1999. During this study, 465 chinook salmon and three rainbow trout (steelhead) were collected. Chinook salmon were found throughout the east and west branches of the Grand Calumet River. Chinook salmon were widely distributed and found throughout both branches to the mouths that form the Indiana Harbor Canal; however, we did not observe any successful reproduction. The presence of salmon in the Grand Calumet River could force changes in designated uses to a more conservative standard that are protective of coldwater fish, thus reducing pollutant inputs into the basin.

Keywords: Spatial distribution, Lake Michigan, fish management, stocking

The probability of salmonid fishes occurring in the Grand Calumet River watershed has been debated within state government, which resulted in the river not being designated a salmonid stream for Water Quality Criteria purposes (IDEM 1996). Chinook salmon (*Oncorhynchus tschawytscha*) is a non-indigenous species of Pacific salmon that was stocked into the Great Lakes as a species management control for alewives (*Alosa pseudoharengus*) and for a sport fishery (Dehring & Krueger 1986). The species has been collected throughout the Indiana tributaries of Southern Lake Michigan; however, few individuals have been observed in the Grand Calumet River (Simon et al. 1989; Simon & Stewart 1998; Simon & Moy 2000). The Grand Calumet River is located in a Great Lakes Area of Concern that has impairment of all 14 designated uses (IJC 1983; U.S. EPA 1985; Simon & Stewart 1998; Stewart et al. 1999; Simon et al. 2002). Spacek (1996) reported spawning salmonids and successful hatching in the West Branch of the Grand Calumet River about 1.6 km upstream from the junction with the East Branch of the Grand Calumet River. This observation would be the first reported spawning occurrence in southern Lake Michigan. Simon and Moy (2000) had previously considered this report unlikely.

Simon et al. (1989) found chinook salmon in the East Branch of the Grand Calumet River near the junction with the West Branch and found rainbow trout (*Oncorhynchus mykiss*) in the Indiana Harbor Canal between 1985–1988. Simon and Moy (2000) reported rainbow trout in the Gary Sanitary District's outfall in 1994. Rainbow trout were also observed there in 1998 and 1999 (Simon unpubl. data). No salmonids had previously been collected in the West Branch of the Grand Calumet River. Although few salmonid fishes have been collected over the last 15 years, attempts to find salmonid fishes between 1985 and 1998 were limited to periods when these species would be less likely to occur due to thermal limitations. The State of Indiana (1999) found no salmonids during a late spring survey of the East Branch of the Grand Calumet River although other thermally-sensitive lake species such as alewife were observed. Despite the information that salmo-

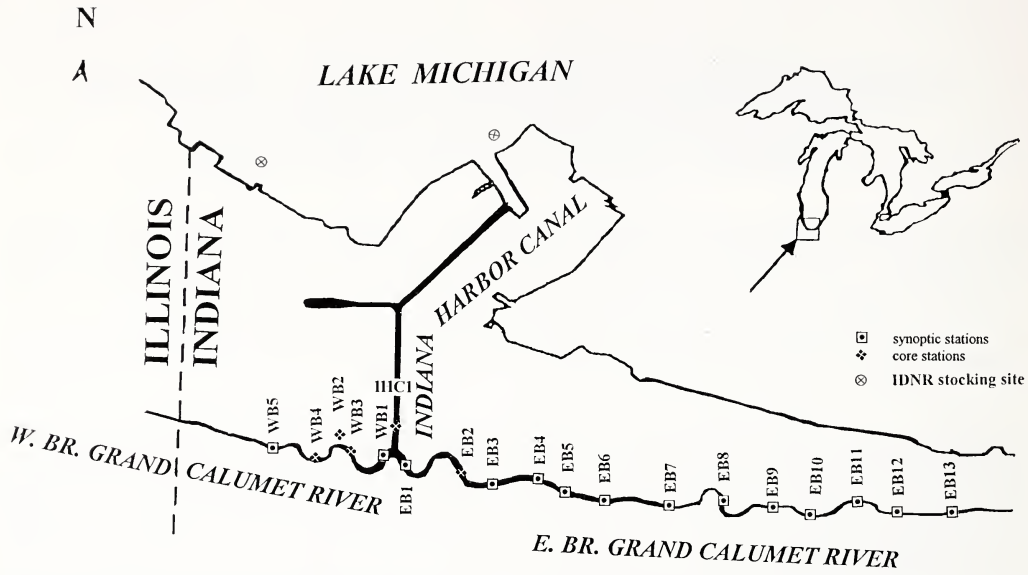

Figure 1.—Location of weekly monitoring reaches (♣) and monthly sampling reaches (⊙) in the Grand Calumet River and Indiana Harbor Canal during an investigation of salmonid fish species distribution performed between September and November 1999. Stocking sites in Lake Michigan are indicated by (⊗).

nids were sometimes present, the State of Indiana and the U.S. Environmental Protection Agency (EPA) granted a permit variance request to a major discharger in the East Branch of the Grand Calumet River. This variance, based on a recalculation of the cyanide standard without the salmonid data, allowed increased concentrations of cyanide to be placed into the river (Dennis Clark, Indiana Department of Environmental Management, pers. commun.).

The purpose of this study was to examine the water quality standard ramifications of salmonid presence in the West Branch of the Grand Calumet River and to authenticate salmonid occurrence and distribution in the remainder of the Indiana portion of the watershed. In addition, we wanted to verify the spawning and successful reproduction of chinook salmon in the East Chicago Sanitary District's discharge canal based on observations by Spacek (1996).

METHODS

Study area description.—The Grand Calumet River basin is a small watershed located in northwestern Indiana (Fig. 1) and encompasses about 17,500 ha contained almost entirely within Lake County, Indiana (U.S. EPA 1985). The Grand Calumet River is about 34 km long and has been designated an Area of Concern by the International Joint Commission (IJC 1989). The Grand Calumet River and Indiana Harbor Canal occupy a low-relief area in the glacial bed of geological Lake Chicago. The general flow is sluggish and westward in the East Branch of the Calumet River, east- or westward in the West Branch depending on Lake Michigan levels, and northward in the Indiana Harbor Canal, an artificial connection to Lake Michigan. Land-use disturbance in the area has been extensive with modification including ditching, channelization, flow modification, development of urban centers, and one of the most concentrated steel and petrochemical industrial complexes in the United States (U.S. EPA 1985). Severe sediment contamination has been documented in the Grand Calumet River and Indiana Harbor Canal, including polycyclic aromatic hydrocarbons (PAH), metals, and oil and grease (Hoke et al. 1993; Ingersoll et al. 2002; McDonald et al. 2002a, b). Surface waters were toxic and teratogenic based on an embryo-larval subchronic teratogenicity test, as a result of effluents emanating from point-source discharges (Simon 1989).

Community collection and reach selection.—Fish communities were sampled at select reaches that were based on previous water and sediment sampling stations above and below point-source discharges in the Grand Calumet River (Simon 1989; Simon et al. 1989; Simon et al. 2002). Five core reaches were evaluated weekly between 25 September and 23 November 1999 to quantify salmonid presence in the vicinity of the West Branch of the Grand Calumet River and Indiana Harbor Canal (Fig. 1). The five reaches sampled weekly were in each of the three tributary units of the Grand Calumet River and Indiana Harbor Canal. Reach WB2 is located in the West Branch of the Grand Calumet River (WBGCR) in the "earthen channel" outfall of the East Chicago Sanitary District; reach WB4 is located in the WBGCR west of Indianapolis Boulevard; reach WB3 is the WBGCR east of Indianapolis Boulevard, which is below the East Chicago Sanitary District's earthen channel outfall; reach IHC1 is located in the Indiana Harbor Canal between the railroad trestle bridge and Columbus Avenue; and reach EB2 is in the East Branch of the Grand Calumet River (EBGCR) west of Kennedy Avenue.

In addition to the five reaches sampled weekly, 14 additional synoptic sites were surveyed monthly for a total of 19 sites (Fig. 1). The WBGCR had five reaches that were distributed between Columbia Avenue and the junction with the East Branch at 1) east of Columbia Avenue (WB5), 2) west of Indianapolis Boulevard (WB4), 3) east of Indianapolis Boulevard (WB3), 4) the East Chicago Sanitary District earthen channel (WB2), and 5) the mouth of the West Branch (WB1). The EBGCR had 13 reaches distributed between Broadway Avenue to the junction with the WBGCR. These reaches included 1) the mouth of the East Branch (EB1), 2) west of Kennedy Avenue (EB2), 3) east of Kennedy Avenue (EB3), 4) west of Cline Avenue (EB4), 5) east of Cline Avenue (EB5), 6) east of Clark Road (EB6), 7) east of Bonji (EB7), 8) west of Bridge Street (EB8), 9) east of Bridge Street (EB9), 10) east of Buchanan Street (EB10), 11) west of Buchanan Street (EB11), 12) east of the triple train trestles of USX (EB12), and 13) west of Broadway Avenue (EB13). A single reach was sampled in the Indiana Harbor Canal during the synoptic and core surveys (IHC1).

Fish species composition and relative abundance (catch-per-unit-of-effort or CPUE is the number of fish/minute of electrofishing effort) data were gathered by performing electrofishing surveys at core and synoptic river reaches using a model 6A Smith-Root boat-mounted electrofisher. Electrofishing surveys included systematic sampling of representative habitats within reaches including the thalweg or deepest point in the cross-sectional profile, usually for distances of 500 m for a minimum of 900 seconds. Captured fish were placed in an onboard holding tank until a sampling event was completed. Data recorded for each survey event included species' identifications and weights, number of fish caught, examination for external disease and anomalies (DELTs), and sample and habitat conditions. Shallow depths in the earthen channel prohibited boat access and inhibited electrofishing after early October. A visual survey of species presence was performed in the earthen channel between 10 October and 23 November 1999 by walking the entire length of the earthen channel and recording the identity and number of observed fish. Water quality data was measured using a Hydrolab datasonde 4a, which measured dissolved oxygen, temperature, pH, specific conductance, oxidation-reduction potential, total dissolved solids, and salinity.

RESULTS AND DISCUSSION

The presence of salmonids in the Grand Calumet River watershed had previously been considered a result of transient individuals occasionally swimming into the river (Simon et al. 1989), while other reports considered their presence and spawning activity highly unlikely (Simon & Moy 2000). The previous absence of salmonids in the Grand Calumet River may actually have been a result of discharge temperatures associated with point sources than any other reason. The State of Indiana granted a variance request allowing increased cyanide discharge based on no records of trout or salmon in the East Branch of the Grand Calumet River. We collected 465 chinook salmon during this study, which negates the belief that these fish are only occasional or rare community components (Table 1). While only three rainbow trout were collected, we consider this the beginning of a fall run and anticipate that more trout would have been collected with continued sampling. Re-

ports of fall run rainbow trout in Trail Creek suggest that this species may be present until late February to mid-March (Brian Breidert, IDNR, pers. commun.). Chinook salmon occurred in the East and West Branches of the Grand Calumet River from the headwaters to the mouth of each branch. We observed only four salmonids in the Indiana Harbor Canal because of its greater depth reduced collection effectiveness; however, our expectation is that salmon use this waterway as the primary dispersal route between the river and Lake Michigan.

Water quality conditions, based on Indiana State Water Quality Standards, were within acceptable limits for salmonids. Dissolved oxygen ranged between 4.6–16.6 mg/L. Our results suggested that temperature limited salmonid entrance into the Grand Calumet River until mid-October, after which temperatures were consistently below 19.5 °C. The apparent reduction in surface water toxins from effluents since 1986 may be the result of more stringent National Pollutant Discharge and Elimination System (NPDES) permits (Ronald Kovach, U.S. Environmental Protection Agency, pers. commun.), which allow chinook salmon to survive in the watershed (Simon 1989). Dissolved oxygen concentrations prior to 1990 were generally below water quality standards (4.0 mg/L) for the Grand Calumet River watershed (STORET unpubl. data). The presence of large numbers of chinook salmon in the East Branch should result in further evaluation of the cyanide variance, possibly causing further modifications before reissuance (Dennis Clark, Indiana Department of Environmental Management, pers. commun.). However, since we found no evidence of reproduction, a compromise position may be to allow the inclusion of adult salmon data in the cyanide calculation but still remove juvenile and smolt toxicity data. No juvenile salmonids were found in over 15 years of effort in the entire Grand Calumet River watershed. In addition, sampling conducted by the Indiana Department of Environmental Management (Newhouse 1999) in the upper East Branch of the Grand Calumet River did not find any salmon; however, other coolwater species such as alewife were collected.

The presence of salmon in the Grand Calumet River could force changes in designated uses to a more conservative water quality standard that is protective of coldwater fish and would result in reduced pollutant inputs into the basin. Currently Grand Calumet River standards are those of a warmwater fishery. Documentation of the high numbers of salmon present should result in changes in the standards to those for a coldwater salmonid fishery.

Spacek (1996) reported reproduction and successful hatching of chinook salmon in the East Chicago Sanitary District's plant at an undisclosed time of the year. Although we attempted to document reproduction during this study, we observed only a single female in the plant's disinfection chamber between 2 October and 25 October 1999. Shallow depths (< 0.3 m) in the earthen channel due to drought conditions may account for this result. Large adult males were photographed swimming in the earthen channel, but no reproductive behavior was observed.

The Indiana Department of Natural Resources (IDNR) has stocked chinook salmon at Whiting and Inland Steel (Fig. 1) annually to supplement stockings further east. Inland Steel, located next to the Indiana Harbor Canal, is the primary stocking site, with a goal of 80,000 chinook salmon annually; and Whiting is the secondary site with a goal of 30,000 chinook salmon (John Kubisiak, IDNR, pers. commun.). These stocking goals have been met over the past several years, with the exception of 1997 when chinook salmon were not stocked at Whiting. Stockings at Inland Steel exceeded the goal and averaged 105,000 chinook annually during this time. None of the chinook salmon stocked by the IDNR at Whiting and Inland Steel between 1996 and 1998 were marked with fin clips, although a clipped adipose fin is the usual mark for Indiana. Several of the fish collected had their left pelvic fin clipped, but none had a clipped adipose fin. This suggests that not all of these fish were returning individuals from IDNR stockings. We suspect that the supplemental Indiana DNR stockings resulted in the successful return of chinook salmon in the Grand Calumet River watershed.

We evaluated the condition of chinook salmon encountered during this investigation. Generally, chinook salmon were in good condition; only one female had severe anal fin erosion. Since cobble and boulder substrates

Table 1.—Relative abundance, catch-per-unit-effort (CPUE-number of fish/per minute of electrofishing time), distribution, and chronological presence of chinook salmon at weekly and monthly survey reaches in the Grand Calumet River and Indiana Harbor Canal between 25 September and 23 November 1999. Dashed lines indicate that sampling was not conducted on that date. No CPUE was calculated for the East Chicago Sanitary District disinfection chamber because electrofishing surveys were not performed inside the wastewater treatment plant. Numbers in brackets refer to locations in Figure 1.

	Sept-ember	October				November			
Reach	25	6	13	18	27	2	10	17	23
West Branch Grand Calumet River									
East Columbia Avenue [WB5]	—	—	—	—	25 (1.67)	19 (1.27)	8 (0.53)	2 (0.133)	2 (0.133)
West Indianapolis Boulevard [WB4]	0	0	0	3 (0.10)	11 (0.73)	9 (0.06)	8 (0.53)	2 (0.13)	2 (0.13)
East Indianapolis Boulevard [WB3]	0	0	0	1 (0.01)	4 (0.27)	7 (0.47)	7 (0.47)	3 (0.20)	4 (0.27)
East Chicago Sanitary District [WB2]	0	1	1	1	1	0	0	—	0
Earthen Channel [WB2]	0	0	0	0	1 (0.07)	1 (0.07)	0	—	0
West Branch mouth [WB1]	0	0	1	0	1 (0.07)	—	5 (0.33)	—	2 (0.13)
Indiana Harbor Canal									
South Columbia Boulevard [IHC1]	0	0	0	0	0	0	2 (0.13)	2 (0.13)	0
East Branch Grand Calumet River									
East Branch mouth [EB1]	0	—	—	1 (0.07)	1 (0.07)	—	5 (0.33)	—	3 (0.20)
West Kennedy Avenue [EB2]	0	0	0	2 (0.14)	2 (0.13)	8 (0.53)	9 (0.60)	1 (0.07)	2 (0.13)
East Kennedy Avenue [EB3]	—	—	—	—	3 (0.20)	—	9 (0.60)	—	2 (0.13)
West Cline Avenue [EB4]	—	—	—	—	3 (0.20)	—	6 (0.40)	1 (0.07)	1 (0.07)
East Cline Avenue [EB5]	—	—	—	—	3 (0.20)	—	3 (0.20)	1 (0.07)	0
East Clark Road [EB6]	—	—	—	—	1 (0.07)	—	10 (0.67)	—	1 (0.07)
East Bonji [EB7]	—	—	—	—	7 (0.47)	—	5 (0.33)	1 (0.07)	3 (0.20)
West Bridge Street [EB8]	—	—	—	—	3 (0.20)	—	15 (1.00)	0	9 (0.60)
East Bridge Street [EB9]	—	—	—	—	4 (0.27)	—	17 (1.13)	—	7 (0.47)
West Buchanan Street [EB10]	—	—	—	—	2 (0.13)	—	23 (1.53)	—	9 (0.60)
East Buchanan Street [EB11]	—	—	—	—	2 (0.13)	—	54 (3.60)	—	19 (1.27)
East Triple Trestle [EB12]	—	—	—	—	3 (0.20)	—	19 (1.27)	—	8 (0.53)
West Broadway Avenue [EB13]	—	—	—	—	15 (1.00)	—	21 (1.40)	—	7 (0.47)
Total by date:	0	1	2	8	92	44	226	13	79
Total at core reaches:	0	0	2	7	19	23	26	8	8

are non-existent in the Grand Calumet River, we speculate that this condition may have been caused by contact with PAH-laden sediments (Ingersoll et al. 2002; McDonald et al. 2002a, b), and about 95% of fish collected during this study were male. About 23% of all chinook salmon collected had either single or multiple lamprey scars. Comparison of the relative weight index for chinook salmon (Murphy et al. 1991) with the Grand Calumet River population shows that Grand Calumet River specimens did not deviate from acceptable condition of the reference index. The fish that were observed during our study ranged from 550–830 mm total length which, based on length-frequency data, suggests that they were between 2–4 years old (Carlander 1969). We suspect that since chinook salmon are known to swim around the entire shoreline of Lake Michigan and do not reside for significant periods of time in the Grand Calumet River nor feed in any appreciable amount during their spawning runs, it would be unlikely that any deviation in either contaminant burden or relative weight from other populations would be observed. However, increased risk to humans would include angler handling, exposure to contaminated water and sediment, and preparation differences (i.e., skin-on versus skin-off filets) of fish. Fish-consumption advisories exist on the entire Great Lakes shoreline in the AOC.

ACKNOWLEDGMENTS

We appreciate the assistance of Pete Baranyai and Dan Olsen (East Chicago Sanitary District) for providing access to the earthen channel and for additional professional courtesies. Scott Davis (Indiana Department of Environmental Management), Joe Exl (IDNR) and Jason Butcher (U.S. Geological Survey, Biological Resources Division) provided field assistance. This study was partially funded by the Natural Resource Damage Assessment fund for the Grand Calumet River. The opinions expressed do not necessarily represent those of the U.S. Fish and Wildlife Service. No official endorsement by that agency should be inferred.

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Manuscript received 20 April 2004, revised 20 July 2004.

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ANURAN HABITAT USE ON ABANDONED AND RECLAIMED MINING AREAS OF SOUTHWESTERN INDIANA

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ABSTRACT. We surveyed wetland habitats on abandoned and reclaimed strip mines in southwestern Indiana to determine species richness and species-habitat relations of anurans at 40 wetland sites during the 2000 breeding season. Nine anuran species were detected, including the state-endangered crawfish frog (*Rana areolata*). Reproduction was confirmed for seven species, and evidence of breeding was detected at all wetland types, both abandoned and reclaimed. Bullfrogs (*Rana catesbeiana*), green frogs (*Rana clamitans*), and Blanchard's cricket frogs (*Acris crepitans blanchardi*) showed preferences for open water habitats relative to ephemeral wetlands. Metamorphs of spring peeper (*Pseudacris crucifer*), southern leopard frog (*Rana sphenocephala*), Fowler's toad (*Bufo fowleri*), Cope's gray treefrog (*Hyla chrysoscelis*), and bullfrog were observed at sediment basin and ephemeral site types. Post-mining landscapes provide opportunity to restore ephemeral habitats and grassland habitats; both are declining due to human land use, and both provide habitat for anurans. Topographic and vegetative heterogeneity on once-mined lands may provide a sufficiently diverse landscape to support the full range of anuran species in the area.

Keywords: Frogs, mining, conservation, habitat use, landscape management

Wetland habitats are lost during coal mining through removal of surface layers and alteration of hydrology. In addition, acid mine drainage makes mined areas inhospitable to wildlife, particularly amphibians, due to low water and soil pH (Andren et al. 1988; Nawrot & Klimstra 1989). However, a variety of wetlands is left behind after mining, and wetlands in which pH is not too low may offer potential wildlife habitat.

Surface mining of coal has been conducted in Indiana since the 1920s. State laws began to address reclamation in 1941. The Surface Mining Control and Reclamation Act (SMCRA) of 1977 resulted in national reclamation standards, but emphasized restoring mined lands to the original land use (e.g., timber production and agriculture), with less emphasis on wildlife habitat development (Nawrot & Klimstra 1989). Nevertheless, actions undertaken through SMCRA can enhance reclaimed mining wetlands by developing the littoral zone and by establishing prairie areas that include ephemeral wetlands (Nawrot & Klimstra 1989; Indiana Department of Natural Resources 1998).

Aquatic vegetation, aquatic invertebrates, and amphibians may colonize newly-reclaimed sedimentation ponds in surface mines within a year of construction (Fowler et al. 1985). In abandoned areas, final-cut lakes, sediment basins, and ephemeral wetlands offer a diversity of microhabitats, are often less accessible to people, and are recolonized by local plant species rather than planted to monotypic crops or pasture vegetation typical of reclaimed areas (Suchecki & Evans 1978; Nawrot & Klimstra 1989).

We investigated anuran use of wetlands on abandoned and reclaimed mines in southwestern Indiana, and we related species presence to habitat parameters. Information on anuran response to wetland parameters can be used for future wetland design in reclaimed mining areas. With global concern about amphibian population decline, exploring habitat availability and quality within reclaimed mining wetland areas can provide valuable information on the usefulness of these areas for amphibian conservation.

METHODS

Abandoned and reclaimed coal mining areas in Daviess, Dubois, Gibson, Green, Knox, Pike, Sullivan, Vanderburgh, and Warrick counties were surveyed during the summer of 1999 (Fig. 1). Reclaimed wetland sites were

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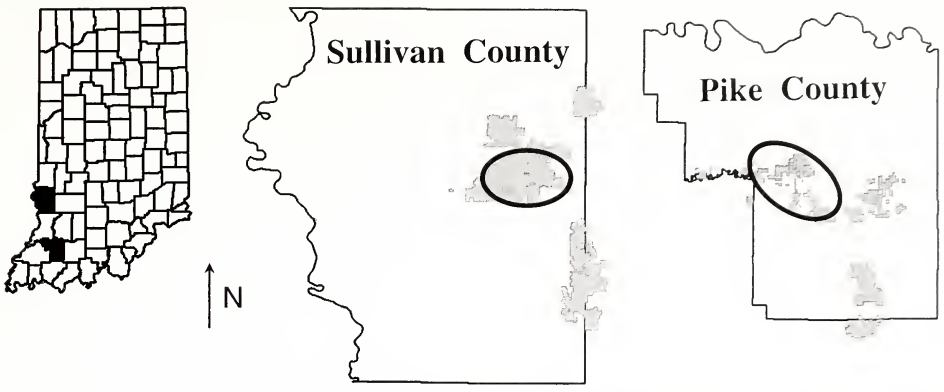

Figure 1.—Study areas in Sullivan County and Pike County, Indiana. Shaded areas show state fish and wildlife areas. Ovals show approximate extent of study.

defined as sites reclaimed according to SMCRA regulations post-1982. Reclamation history was determined for each wetland, and water pH was measured. Sites with pH < 5 were not used because studies have shown that lower pH values harm or kill frog eggs and larvae (Andren et al. 1988). Less than 1% of 52 sites we considered had pH < 5, with the lowest pH at 2.8.

We selected two study areas in the region described above. In each area, we established a call monitoring route with listening points placed to allow calls to be assigned unambiguously to a single wetland, lake, or bottomland site. The Minnehaha study area consisted of 23 sites in Sullivan County and site locations in the Minnehaha Fish and Wildlife Area and Kindall Mining Company mines, near Dugger, Indiana. Mines in this study area were active from about 1960–1980. The Patoka study area of 17 sites in Pike County included site locations in Black Beauty Coal Company mines, Sugar Ridge Fish and Wildlife Area, and Patoka River National Wildlife Refuge and Management Area, near Oakland City, Indiana. Mines in the Patoka study area were active from about 1930–1950 and again in the 1990s. The Patoka study area included two naturally-occurring wetlands that had never been mined (Snaky Point Marsh and an oxbow of the Patoka River). The Minnehaha site had two wetlands that had never been mined, but both were substantially affected by mining activity.

Wetland sites within the study areas were categorized as final-cut lakes, sediment basins, or ephemeral sites. A final-cut lake is a permanent aquatic site that results from the final removal of surface layers to extract coal from a coal layer. A sample of final-cut lakes in the study area for which we could obtain data had an average surface area of 11.45 ha. A final-cut lake encompasses the access road into the pit, as well as the last portion of the pit, which typically was not refilled when work on the pit ended. Depth of final-cut lakes varies from shallow water over the access road to depths > 30 m over the steep-walled, abandoned pit (Carter et al. 1974). Sediment basins are semipermanent to permanent ponds or wetlands that are designed to collect sediment and debris from the mining site (Rowe 1979). Sediment basins in our study area averaged 3 ha in area and 5 m in depth. Ephemeral sites, as defined for this study, are depressional wetlands that hold water only part of the year and that do not have inflow from or outflow to a stream or lake (National Research Council 2001); all our examples of this type were $\leq$ 0.3 ha in size. Ephemeral sites are not created deliberately but rather occur when heavy clay soils retain water wherever depressions happen to occur. The final selection of study sites encompassed six abandoned and one reclaimed sediment basin at Minnehaha and five abandoned and six reclaimed sediment basins at Patoka; three abandoned and three reclaimed ephemeral sites at Minnehaha and two abandoned and no reclaimed ephemeral sites at Patoka; nine abandoned and one reclaimed final-cut lakes at Minnehaha and four abandoned and no reclaimed final-cut lakes at Patoka.

Call surveys were conducted from 24 Feb-

ruary to 10 August 2000 on nights following rain, with temperatures above 12.7 °C, relatively high humidity, and good listening conditions. Call surveys at each study area started after sunset and followed the same route between the sites for 2.5–3 hours (3 minutes per listening station) for all surveys. Larger wetland sites had multiple call survey points to ensure detection of all species present. North American Amphibian Monitoring Program (NAAMP) call index values were assigned for all species at all stations: 0 (no frogs of given species calling), 1 (individuals discernable with space between calls), 2 (calls of individuals discernible but some overlapping), or 3 (full chorus, calls constant and continuous). Where multiple wetlands occurred in close proximity, we selected listening stations that would permit frogs to be correctly assigned to the surrounding wetlands.

Tadpole surveys were conducted to confirm successful anuran reproduction at study sites. Surveys were conducted from March to August 2000 using dip nets, minnow traps, and seines. When possible, tadpoles were identified to species according to morphological characteristics and timing of breeding cycle (Altig et al. 1998). Predators observed while surveying and trapping were noted.

We visually estimated percent perimeter coverage of wetland and upland vegetation around the perimeter of each wetland site. Percent cover of tall emergent, short emergent, floating leaf shoreline vegetation, and unvegetated shoreline were recorded. Percent cover of closed (tree), mixed tree (tree, shrub, and herbaceous), and mixed shrub (shrub and herbaceous) cover types were estimated in a 20 m band around each site. The 20 m distance was assumed to be cover utilized by anurans that may use upland habitats (e.g., Blanchard's cricket frogs (*Acris crepitans blanchardi*), southern leopard frogs (*Rana sphenocephala*), and Cope's gray tree frogs (*Hyla chrysoscelis*)).

For statistical purposes, a species was considered present if it was heard calling at any call index level > 0. Tests were considered significant when $P \leq 0.05$. We used contingency-table tests to compare call frequencies among frog species and among site types; the null hypothesis for these tests is that, for the species in question, the calling intensity was independent of wetland type.

Tests of habitat relations were conducted with the two study areas combined as there was no reason to suppose relationships would be location-specific. We did not test for habitat relationships for crawfish frogs due to low numbers of observations of this species. We used Spearman rank correlations to identify relationships between species presence and vegetative cover types as there was no *a priori* reason to expect such associations to be linear. Mann-Whitney U and Kruskal-Wallis tests were conducted to identify differences in proportion of wetland and upland vegetative cover types (Ambrose & Ambrose 1995); data did not regularly meet assumptions for t-tests and one-way ANOVAs; we report Z statistics for these tests. Subscripts of M and P are used to denote statistical results from the Minnehaha and Patoka study sites, respectively. We used contingency-table tests to test for selection among ephemeral, sediment-basin and final-cut sites by each anuran species by determining whether the observations of calling frogs were distributed as expected based on the proportions (availability) of the three site types.

We report species richness findings but do not present statistical tests because sample sizes were too small. Due to the introductory nature of this research, some exploratory statistical results are discussed.

RESULTS

Species richness.—Nine anuran species were detected during this study: bullfrog (*Rana catesbeiana*), chorus frog (*Pseudacris triseriata*), Cope's gray treefrog, Blanchard's cricket frog, Fowler's toad (*Bufo fowleri*), green frog (*Rana clamitans*), southern leopard frog, spring peeper (*Pseudacris crucifer*), and the crawfish frog (*Rana areolata*), a state-listed endangered species. Of these, all were detected at Minnehaha, and all but the crawfish frog were detected at the Patoka study area. At abandoned sites at both study areas, total species richness at ephemeral sites (the species count across all ephemeral sites) was lower than at sediment basins and final-cut lakes (Table 1). However, differences between the least and most rich categories were only one and three species at Patoka and Minnehaha, respectively. Median species richness was also lowest at ephemeral sites at Patoka. At Minnehaha, median species richness differed by only a single species among ephemeral, sedi-

Table 1.—Anuran species richness at wetland sites on reclaimed and unreclaimed areas within the Minnehaha and Patoka study areas in southwestern Indiana. Entries show range of species richness within a category, median species richness, total species richness within the category, and sample size. For categories with $n = 1$, medians and totals are not shown. Categories with no sites are shown as "nd."

	Minnehaha		Patoka	
Wetland type	Abandoned	Reclaimed	Abandoned	Reclaimed
Sediment basin	5–7, 6, 9 (6)	8 (1)	1–6, 5, 8 (5)	4–6, 5, 8 (6)
Ephemeral	2–6, 5, 6 (3)	3–7, 3, 7 (3)	1–7, 4, 7 (2)	nd
Final cut	2–8, 5, 9 (9)	8 (1)	5–7, 6, 8 (4)	nd

ment basin, and final-cut sites. Sample sizes from reclaimed sites were too small to permit comparison. The naturally-occurring wetlands that had never been mined in Patoka (a marsh and an oxbow wetland) supported eight of the nine species in the region; crawfish frogs, which prefer grassland sites, were absent.

Species preference for ephemeral, sediment basin, and final-cut sites.—Bullfrogs, green frogs, and Blanchard's cricket frogs all used final-cut sites in higher proportions than expected, and ephemeral sites in lower proportions ($\chi^2 = 20.327$, $df = 2$, $P < 0.001$; $\chi^2 = 9.812$, $df = 2$, $P = 0.007$; $\chi^2 = 18.307$, $df = 2$, $P < 0.001$). Other significant, but less pronounced, preferences were shown by Fowler's toad (avoiding ephemeral sites: $\chi^2 = 6.305$, $df = 2$, $P = 0.043$) and southern leopard frog (tendency to prefer sediment basins and final-cut lakes: $\chi^2 = 6.49$, $df = 2$, $P = 0.039$).

Upland and wetland cover.—The three upland and four wetland cover types generally did not differ significantly in their proportions within a wetland site type between the Patoka and Minnehaha study areas, or within a study area, tested among wetland site types (each upland and wetland cover type was tested separately). The Patoka study area had significantly higher estimated tree cover around final-cut sites than the more recently mined Minnehaha study area (Mann-Whitney U test: $Z = -1.957$, $n_M = 10$, $n_P = 4$, $P = 0.05$) and nearly significantly greater tree cover at ephemeral sites (Mann-Whitney U test: $Z = -2.619$, $n_M = 6$, $n_P = 2$, $P = 0.07$). Within the Patoka study area, sediment basin sites had lower tree cover than final-cut or ephemeral sites ($\chi^2 = 6.21$, $df = 2$, $P = 0.045$). Sediment basin sites had more tall emergent cover than the other two wetland types ($\chi^2 = 6.524$, $df = 2$, $P = 0.038$) when the study areas were combined (no between-study-area differences were significant).

Species–wetland habitat relationships.—Number of detections of Blanchard's cricket frogs was positively associated with total wetland vegetation in sediment basin sites ($i_s = 0.680$, $n = 18$, $P = 0.002$) and ephemeral sites ($i_s = 0.770$, $n = 8$, $P = 0.025$), but not at final-cut sites where wetland vegetation was rare (median proportion of shoreline in wetland vegetation = 0, $n = 14$). Fowler's toads were strongly associated with total wetland vegetation at sediment basin sites only ($i_s = 0.601$, $n = 18$, $P = 0.008$). Other correlations were either not significant, or were inconsistent among wetland types.

Predators.—The following vertebrate predators were observed: raccoon (*Procyon lotor*), great blue heron (*Ardea herodias*), green heron (*Butorides striatus*), rainbow trout (*Oncorhynchus mykiss*), largemouth bass (*Micropterus salmoides*), sunfish (*Lepomis* spp.), mosquitofish (*Gambusia affinis*), minnows (Cyprinidae), water snakes (*Nerodia sipedon*), midland painted turtle (*Chrysemys picta marginata*), red-eared slider (*Trachemys scripta elegans*), common snapping turtle (*Chelydra serpentina serpentina*), and western lesser siren (*Siren intermedia nettingi*). The following invertebrate predators were also observed: crayfish (Decapoda), dragonflies (Anisoptera), predaceous diving beetle (Dytiscidae), giant water bug (Belostomatidae), water scorpion (Nepidae), and dobsonfly (Corydalidae). Ephemeral sites generally only had invertebrate predators such as predaceous diving beetle, crayfish, and dragonflies, whereas final-cut and sediment basin sites had vertebrate predators such as fish, snakes, and turtles. Fish were present at 86% of final-cut sites and 72% of sediment basin sites.

Evidence of breeding.—Evidence of hylid

Table 2.—Evidence of hylid and ranid breeding at all wetland types at the Minnehaha and Patoka study areas (Rl = ranid larvae; Rm = ranid metamorphs; Hl = hylid larvae; Hm = hylid metamorphs). Categories with no sites are shown as "nd."

	Minnehaha		Patoka	
Wetland type	Abandoned	Reclaimed	Abandoned	Reclaimed
Sediment basin	Rl, Hl, Rm	Rl	Rl, Hl, Rm, Hm	Rl, Hl
Ephemeral	Rl, Hl, Rm, Hm	Rl, Hl	—	nd
Final cut	Rl, Hl	—	Rl, Rm	nd

and ranid breeding was detected at all wetland site types and in both reclaimed and abandoned sites (Table 2). Larvae were present at 29% of 14 final-cut sites, 44% of 18 sediment basin sites, and 50% of 8 ephemeral sites. Spring peeper, southern leopard frog, and bullfrog metamorphs were observed at ephemeral sites at the Minnehaha study area. Fowler's toad and southern leopard frog metamorphs were observed at sediment basin sites at the Minnehaha study area. Cope's gray treefrog metamorphs were observed at a sediment basin site at the Patoka study area.

DISCUSSION

Presence of nine frog species and evidence of breeding for both hylid and ranid species at all types of wetland sites demonstrate that surface mining landscapes offer habitat for Indiana anuran species. Observation of metamorphs further indicates the conservation potential of reclaimed and unreclaimed mining sites. Of the species potentially resident at the two study sites, but not found during this study, the eastern spadefoot is a species of special concern in the state and has not actually been observed in either county. Wood frogs have not actually been observed in either county, but they are relatively common in the region and may have been missed due to their short, early calling window.

The herpetofauna at abandoned mines in southern Indiana was known to approximate richness and abundance of adjacent cropland and natural areas (Suchecki & Evans 1978), but this is the first study to demonstrate high richness (relative to potential richness) at more recently disturbed (1990s) reclaimed areas in Indiana. Studies on newly reclaimed (1980s) sedimentation ponds in Tennessee have documented similar anuran richness (10 species; Fowler et al. 1985); we provide further evidence of breeding for seven anuran species at both sediment basin and ephemeral sites. Less than 1% of sites investigated for selection in our study had pH < 5; and the limestone-based soils in southern Indiana may improve chances for full remediation of acid mine drainage, and increase the likelihood of amphibian recolonization.

Habitat relationships documented during this study confirm that anurans on mined areas continue to show the habitat behavior observed in more traditional settings. Bullfrogs and green frogs are known to favor open water, and although cricket frogs are less strongly linked to permanent open water, they are not considered to favor ephemeral areas (Minton 2001). The only links to vegetation-B-Blanchard's cricket frog and Fowler's toad to wetland vegetation cover—may simply have been a response to value of the vegetation as escape cover. The greater tree cover found in the vicinity of sites at the less-recently-mined Patoka study area did not alter species richness relative to the more-recently-mined Minnehaha study area: both study areas had essentially the full species complement they might be expected to support.

Possibly, the topographic variation that results from mining, and the eventual vegetative heterogeneity, whether from natural processes or from reclamation, provide a sufficiently diverse landscape to support breeding, nonbreeding, and corridor habitat for the full range of anuran species (Kolosvary & Swihart 1999; Knutson et al. 2000). In particular, mining landscapes may provide more of one limiting habitat type—ephemeral wetlands—than most other land uses.

As mining spoil is removed and replaced as a part of the mining process, swale areas can result through incomplete filling between spoil piles, which in turn results in ephemeral wetlands. Thus, ephemeral wetlands can be rather

common on once-mined lands, although they are seldom created purposefully (Deanna Luzynski, Indiana Division of Reclamation; Bernie Rottman, Black Beauty Coal Company, pers. commun.).

Small isolated or ephemeral wetlands are becoming increasingly rare elsewhere in human-dominated landscapes, due to filling and draining (Lehtinen et al. 1999); mining landscapes may offset some of this loss (Dodd & Cade 1998). Ephemeral or semi-permanent wetland areas can support high levels of amphibian species richness and are important for breeding and recruitment (Dodd & Cade 1998; Semlitsch & Bodie 1998; Kolozsvary & Swihart 1999; Nyberg & Lerner 2000). Additionally, isolated ephemeral wetlands improve connectivity and reduce migration distances to breeding sites (Semlitsch & Bodie 1998). Habitat connectivity is known to be a limiting landscape feature for amphibian dispersal and for recovery of disturbed or extirpated populations (Semlitsch 2000).

Grassland habitats are also enhanced on restored mined lands; whereas elsewhere in Indiana, prairies have been almost entirely converted to row crops and pasture (Jackson 1997). The state-endangered crawfish frog's former range in Indiana was restricted to prairie and prairie-forest ecotone in the western part of the state (Minton 2001). Regionally, habitat loss due to development and agriculture has led to population declines for this species in Illinois, Indiana, Iowa, Kansas, and Missouri (Redmer 2000). However, restoration activities on mine lands tend to create grassland cover more commonly than tree cover (Bajema et al. 2001). Mine lands in Indiana now provide over 180 sq km of grassland habitat, and have become important conservation areas for grassland birds displaced from their original habitats by agriculture (Bajema et al. 2001). Crawfish frogs, too, may actually be favored by restoration of mine lands to grassland cover.

The presence of fish in 86% of the final-cut sites and 72% in the sediment basin sites has potential to diminish amphibian breeding success. Largemouth bass feed heavily on tadpoles (Hamilton & Powles 1997), and mosquitofish are known to consume frog eggs (McDiarmid & Altig 1999). The effects of stocking of largemouth bass, sunfish, and mosquitofish on amphibians should be considered when managing the landscape for amphibians. Enhancement of wetlands that do not contain fish should be considered.

Based on the findings of this study, considerations for amphibians in wetland design for reclaimed landscapes include: (1) preservation/enhancement of ephemeral areas within the landscape; (2) enhancement/restoration of grassland habitat, possibly in the same swale areas that favor ephemeral wetlands; and (3) maintaining a variety of wetland habitat types and wetland complexes, with and without fish, within the mining landscape.

ACKNOWLEDGMENTS

We thank Deanna Luczynski, Indiana Division of Reclamation, for help with site selection and reclamation history. Bernie Rottman, Black Beauty Coal Company, and Don Mann, Kindall Mining Company provided access to private land and reclamation history. Information on land use and history of designated wildlife areas was provided by: Ron Ronk, Minnehaha Fish & Wildlife Area, John Wade, Sugar Ridge Fish & Wildlife Area, and William J. McCoy, Patoka River National Wildlife Refuge. We thank Michael Lodato, Dr. Spencer Cortwright, Dr. Chris Craft, and Dr. Craig Nelson for herpetological, wetland, and logistical advice and Dan Corcoran, Wes Steiner, Gretchen Schenk, Teresa Ellis, and Erik Osnas for help with fieldwork. We thank two anonymous reviewers and Dr. James Berry for comments on and Meredith Whitney for editorial assistance with the manuscript. The project was funded by grants from the Indiana Academy of Science, American Museum of Natural History, U.S. Fish and Wildlife Service, and Indiana University, Bloomington Graduate Student Organization.

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Manuscript received 4 January 2004, revised 16 August 2004.

2004. Proceedings of the Indiana Academy of Science 113(2):147–150

NATURAL HISTORY DATA ON THE MOLE SALAMANDER (*AMBYSTOMA TALPOIDEUM*) IN INDIANA

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ABSTRACT. Mole salamanders, *Ambystoma talpoideum*, are found primarily in the Coastal Plain of the southeastern United States and are not known to occur in Indiana. From 20–24 March 2004, we captured 24 mole salamanders in a bald cypress (*Taxodium distichum*) swamp in Posey County, Indiana (USA) using minnow traps. We provide baseline data regarding size, sex ratios, migration dates, and breeding status. Our data are similar to those found in other studies on populations within the core of the mole salamander's distribution. This likely represents a disjunct population on the northern limits of the species range. Future surveys need to be conducted to determine if additional populations exist that can bridge the distributional gaps between Indiana, Illinois and Kentucky.

Keywords: *Ambystoma talpoideum*, Indiana, mole salamander, morphology

The mole salamander, *Ambystoma talpoideum*, is found throughout much of the U.S. southeastern Coastal Plain with several small disjunct populations to the north. It also can be found along a northward extension of the Mississippi River drainage from Louisiana to southern Illinois. There are no known records of the mole salamander in Indiana (Minton 2001; Simon et al. 2002). Herein, we describe a small disjunct population of *A. talpoideum* in the extreme southwestern portion of Indiana, which may represent the northernmost population yet recorded.

In general, the mole salamander is a small, stout-bodied salamander with a broad rounded head, short tail and large limbs (Conant & Collins 1998; Petranka 1998; Powell et al. 1998). The body color is variable and is often brownish, grayish or blackish with scattered clusters of bluish-white flecks that tend to be smaller and more concentrated on the back and tail, but may form large blotches on the sides giving a lichen-like effect (Bishop 1943). Adults generally grow to a size of 8–12 cm and can live up to 6–8 years (Raymond & Hardy 1990; Semlitsch et al. 1993).

Most of our knowledge regarding the natural history of the mole salamander comes from research on populations found within the core of its range, while little information is known from the smaller disjunct populations. Moreover, detailed studies of geographic variation in morphology and life history for this species are lacking altogether (Petranka 1998).

The objectives of this report are: 1) to provide preliminary natural history information on this newly discovered and rare species in Indiana, and 2) to compare the body size and habitat data of the Indiana population to those within the core of its distribution.

METHODS

The study site was a permanent shallow wetland complex dominated by bald cypress (*Taxodium distichum*), swamp cottonwood (*Populus heterophylla*) and overcup oak (*Quercus lyrata*) in Posey County, Indiana (Figs. 1, 2). The wetlands were in close proximity to one another and separated by an area of southern flatwoods which consisted mainly of swamp white oak (*Q. bicolor*), shagbark hickory (*Carya ovata*), cherrybark oak (*Q. pagoda*), and pin oak (*Q. palustris*).

In the Spring of 2004, we placed plastic minnow traps at the bases of trees and along fallen logs throughout the swamps. We placed traps at differing water depths ranging from completely submerged (i.e., under approximately 25–30 cm of water) to less than 10 cm of water.

From 20–22 March 2004, we set 28 minnow traps and checked the traps twice daily. On 23–24 March 2004, we set 41 minnow

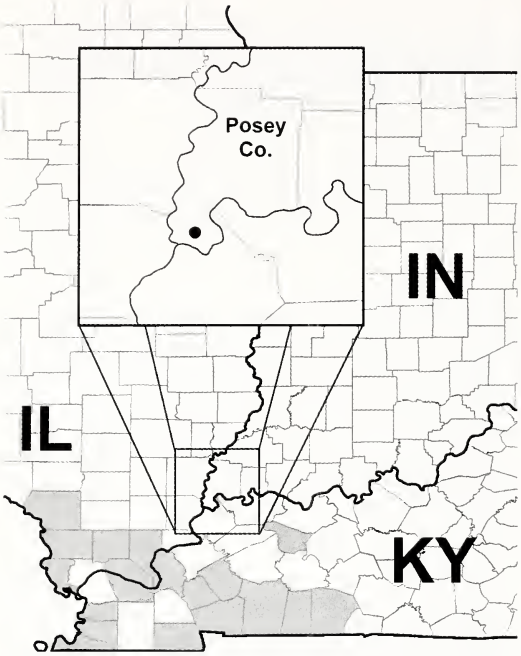

Figure 1.—Location of the mole salamander (*Ambystoma talpoideum*) in Indiana. The black dot represents the approximate location of the mole salamander (*Ambystoma talpoideum*) population in Posey County, Indiana. The shaded regions represent known populations in neighboring areas of Illinois and Kentucky.

traps which we checked once daily. We recorded all amphibian species captured during the trapping period. Each mole salamander captured was weighed (to nearest 0.1 g), measured (to nearest 1.0 mm) to obtain both total and snout-vent lengths (SVL) and classified to sex. We used cloacal swellings and the presence of granular regions on the dorsolateral regions of the tail to classify individuals as breeding adult males (Petranka 1998). Any individual with a SVL $>$ 43 mm and lacking both the swollen vent and granular regions on the tail was classified as a breeding adult female (Semlitsch 1985). *T*-tests were used to determine if males or females differed significantly in size (i.e., SVL, total length, and mass). A chi-squared test was used to determine if the observed sex ratio significantly departed from parity.

Three voucher specimens were collected from the study site. An adult male and an adult female were deposited in the Field Museum of Natural History, Chicago, Illinois.

Figure 2.—Habitat of the mole salamander (*Ambystoma talpoideum*) in Posey County, Indiana.

The remaining voucher specimen, an adult male, was deposited in the Purdue University zoological collection within the Department of Forestry and Natural Resources (Williams & MacGowan 2004).

RESULTS

Males outnumbered females 1.4:1 and did not significantly differ from parity ($\chi^2 = 0.73$, $df = 1$, $P = 0.39$). We captured 22 terrestrial adults (13 males and 9 females), one (presumably recent) metamorph of unknown sex, and one potentially branchiate adult of unknown sex. The SVL and total lengths for the 22 terrestrial adults captured ranged from 45–60 mm and 86–109 mm, respectively (Table 1). The weight of the 22 terrestrial adults captured ranged from 3.5–10.5 g (Table 1). No significant difference was found for the SVL ($t = 0.13$, $df = 20$, $P = 0.89$), TL ($t = 1.10$, $df = 20$, $P = 0.28$) or mass ($t = 0.59$, $df = 20$, $P = 0.55$) between males and females. No body size data was collected on the suspected branchiate adult. Neither the metamorph nor the suspected branchiate adult was included in any of the analyses.

We captured a total of seven amphibian species within the wetland complex: mole salamander, eastern newt (*Notophthalmus viridescens*), smallmouth salamander (*Ambystoma texanum*), marbled salamander (*Ambystoma opacum*), western lesser siren (*Siren intermedia*), chorus frog (*Pseudacris triseriata*), and southern leopard frog (*Rana utricularia*).

DISCUSSION

The mole salamander in Indiana may serve as the northernmost population and is likely

Table 1.—Data taken on the mole salamander (*Ambystoma talpoideum*) from 20–24 March 2004 in Posey County, Indiana (SVL = snout-vent length and TL = total length). *Not included in calculation of means, chi-squared tests or *t*-test. **No data collected.

Individual	SVL (mm)	TL (mm)	Mass (g)
Males			
1	56	106	8.5
2	55	103	9.0
3	55	103	8.0
4	55	102	9.0
5	54	97	7.0
6	53	105	7.5
7	51	100	6.5
8	50	102	7.5
9	50	102	6.5
10	50	100	6.5
11	50	92	6.0
12	47	91	5.5
13	46	92	4.5
Females			
1	60	109	10.5
2	57	98	9.5
3	55	101	8.0
4	50	102	8.0
5	50	101	7.0
6	49	92	7.0
7	49	90	7.0
8	48	88	4.5
9	45	86	6.0
Metamorph*	41	77	3.5
Branchiate adult*	**	**	**
Male mean	51.7	99.6	7.1
Female mean	51.4	96.3	7.5

isolated from other populations. Its discovery allows us to collect baseline data for comparison with populations in other parts of its range. The habitat in which the Indiana breeding population was found is similar to those sites in core areas that consist of extensive floodplain forests located near gum and cypress swamps (Semlitsch 1981; Shoop 1960). The lengths of the Indiana mole salamanders and the lack of morphological difference between sexes ($P = 0.28$) also are consistent with measurements reported from populations within its core distribution (Raymond & Hardy 1990). According to Petranka (1998), adults generally emigrate from the breeding ponds in March. Some adults ($n = 6$) from the Indiana population were observed under cover objects in the surrounding floodplain forests on 7 April 2004 (Z. Walker & M. Ladato pers. commun.), suggesting a similar emigration pattern.

Twenty-two adults were captured and clearly were in breeding condition. Moreover, Z. Walker (pers. commun.) found mole salamander larvae within the wetland on 16 June 2004. The presence of larvae strengthens the premise that the adult salamanders we collected represent a breeding population. The gilled specimen captured on 22 March 2004 was probably a branchiate adult and not an overwintering larva, but no data were collected for confirmation prior to release. Branchiate adults are more common in permanent wetlands while terrestrial adults are frequently found in ephemeral wetlands (Scott 1993; Semlitsch & Gibbons 1985). The permanency of bald cypress wetlands makes a suitable habitat for branchiate adults (Semlitsch 1981).

The mole salamander is likely limited to the extreme southwestern portion of Indiana due to its habitat requirements, but further studies are required to confirm this. The cypress wetlands, the preferred habitat of this species, are extremely rare and fragmented in Indiana. Surveys need to be conducted to determine if additional populations exist that can bridge the gaps between the Indiana population and neighboring populations in Illinois and Kentucky.

ACKNOWLEDGMENTS

We thank Zachary Walker, Mark Pochon, Roger Hedge, and Nate Engbrecht of the Indiana Department of Natural Resources for access to sampling sites and field assistance. We especially thank Z. Walker for assistance with species identification and comments on the manuscript, and M. Pochon for providing lodging while field work was being conducted. Ray Semlitsch of the University of Missouri-Columbia, Alan Resetar of the Chicago Field Museum of Natural History, Robert Brodman of Saint Joseph's College, and Mike Ladato provided assistance with species identification. Purdue University Department of Forestry and Natural Resources provided funds to conduct the field sampling. J.A. DeWoody and members of his lab group provided many helpful comments on earlier drafts of this manuscript. This manuscript is

ARP contribution #17380 from Purdue University.

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Manuscript received 13 July 2004, revised 9 September 2004.

2004. Proceedings of the Indiana Academy of Science 113(2):151–161

BATS OF THE INDIANAPOLIS INTERNATIONAL AIRPORT AREA, 1991–2001

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ABSTRACT. The Indianapolis International Airport (IND) is just west of Indianapolis and just north of Highway I-70 in Marion County. These bats have been studied since 1991 and comprise a diverse community of nine species, listed in approximate decreasing order of abundance: the big brown bat (*Eptesicus fuscus*), the northern myotis (*Myotis septentrionalis*), the eastern red bat (*Lasiurus borealis*), the little brown myotis (*Myotis lucifugus*), the federally-endangered Indiana myotis (*Myotis sodalis*), the state-endangered evening bat (*Nycticeius humeralis*), the eastern pipistrelle (*Pipistrellus subflavus*), the hoary bat (*Lasiurus cinereus*), and the silver-haired bat (*Lasionycteris noctivagans*). Our evidence indicates that all of these species produce young on site except for the silver-haired bat, which is a spring and fall migrant and has its young to the north of Indiana. The northern myotis occupies many of the artificial bat boxes on site.

The Indiana myotis was discovered on the property in 1994; and in 1996 a maternity roost was located in a shagbark hickory tree (*Carya ovata*) in a nearby woodlot, which we now refer to as Sodalis Woods. This tree served as the Indiana myotis primary roost until it fell during the winter of 2001–2002. Several alternate trees were sometimes used as roosts. Evening bats occupied a woodlot north of I-70 but moved into Sodalis Woods when their original lot was developed in the winter of 1997–98.

Keywords: Bats, Chiroptera, Indiana, roosts

The Indianapolis International Airport (IND) is managed by the Indianapolis Airport Authority (IAA) and is located in a rapidly developing area on the southwest side of Indianapolis, Indiana. The bats there have been studied since 1991 in a series of mostly unpublished reports. In 1991, the IAA planned to begin construction of a very large new United Airlines Regional Service Hub. For this work the area had to be surveyed for the federally-endangered Indiana myotis (*Myotis sodalis*) between the dates of 15 May–15 August. However, this date had passed, and construction could not be delayed until 1992. Therefore, IND entered into an agreement with the U.S. Fish and Wildlife Service to assume that the Indiana myotis was present on the study site and to mitigate for potential habitat losses that might occur because of construction. Development and implementation of the mitigation plan was contracted to a private consulting firm. The plan included regular mist-net surveys in areas near the new service hub, planting of new woodlands and wetlands to replace those lost to construction, placement and monitoring of a large number of artificial roost structures for bats (bat-houses, etc.), and radiotelemetry of any Indiana myotis captured during the study. However, a preliminary survey was conducted just after the 15 August deadline, from 20–22 August 1991. A total of 54 bats was captured at five sites as follows: big brown bat (*Eptesicus fuscus*), 38; red bat (*Lasiurus borealis*), 8; northern myotis (*Myotis septentrionalis*), 7; and eastern pipistrelle (*Pipistrellus subflavus*), 1. In 1994, three Indiana myotis were captured, but they roosted on private land and access to the property was denied. However, access was attained in 1996, and radiotelemetry of two Indiana myotis captured that year resulted in the discovery of a roost in a shagbark hickory, *Carya ovata*, in a woodlot just south of the I-70 highway. This woodlot is now termed Sodalis Woods.

Beginning in 1997, responsibility for mon-

itoring the bat community passed to American Consulting Engineers, Inc. (ACE), who subcontracted the bat studies to Indiana State University for the 1997–1999 field seasons. No official monitoring occurred in 2000 or 2001, although university personnel carried on limited work in that period.

Additional construction is now occurring at and near IND, including development of a new interchange at Six Points Road and the re-routing of a section of the East Fork of White Lick Creek. This work necessitated the formulation of a habitat conservation plan (HCP). The HCP was completed by ACE and the bat study was then contracted directly to Indiana State University beginning in 2001. The main purpose of this paper is to summarize information concerning the bat community at the Airport through 2001.

Since the bats at IND will be studied into the foreseeable future, it seemed wise to summarize present data for comparative purposes. Therefore specific objectives of this study were to learn about the roosting and foraging behavior, and habitat of the Indiana myotis and other species of bats in the Indianapolis International Airport study area. Another objective is to determine relative population size of the species within the bat community at the airport. These data are to serve as base data for long-term comparison as further development takes place in and around the airport.

METHODS

Study site.—The airport study site consists of many small, scattered woodlots, up to about 30–40 ha in size, which are surrounded by a mix of agricultural, industrial, and residential areas (Fig. 1). The study area extends from highway US 40 on the north to highway IN 67 on the south, and from IN 267 east to the Indianapolis airport; and I-70 bisects the study area from east to west. However, most of the area north of I-70 has been developed; and, therefore, much of the work is now carried out south of I-70. At times bats are followed to roosts outside of this area.

The East Fork of White Lick Creek, a medium-sized perennial stream, bisects the study area from north to south, from I-70 at Six Points Road to the east side of Mooresville. The wooded banks of White Lick Creek are mostly: box elder (*Acer negundo*); cottonwood (*Populus deltoides*); hackberry (*Celtis occidentalis*); sycamore (*Platanus occidentalis*); green ash (*Fraxinus pennsylvanicus*); black walnut (*Juglans nigra*); and American elm (*Ulmus americana*). In the woodlots on the site, oaks and hickories are generally dominant. Important tree species are: red oak (*Quercus rubra*); white oak (*Quercus alba*); shagbark hickory (*Carya ovata*); shellbark hickory (*Carya laciniosa*); bitternut hickory (*Carya cordiformis*); black walnut (*Juglans nigra*); sugar maple (*Acer saccharum*); American elm (*Ulmus americana*), and honey locust (*Gleditsia triacanthos*). Open areas are mostly cultivated. As part of the mitigation procedures, the airport is purchasing property and planting trees along the East Fork of White Lick Creek.

Mist-netting.—The bat community was assessed annually by mist-netting at ten sites along the East Fork of White Lick Creek. Each netting usually included 1-3 nets placed so as to seal the flyway over the stream. Starting at dusk all sites were netted with two or three tier 9 m × 2 m mist-nets suspended by a pole and pulley system. Nets reached a height of 4 or 6 m. A bat detector was used as a measure of the amount of activity present at a site. Nets along the creek were left in place until at least 2400 h, or until 0200 h if sufficient bat activity occurred. Mist-netting was used (1) to obtain information about the overall bat community, especially concerning changes in populations; and (2) to capture Indiana myotis and other species to radio tag and obtain information about roosting and foraging patterns.

In addition, netting near (but at least 20 m from) Indiana myotis roost trees was initiated in 1996 specifically to increase the number of Indiana myotis captured for radio-tagging and telemetry studies. Netting at these sites was conducted from dusk until bat activity decreased; the nets were then bunched and reopened before dawn to capture bats returning to the roost.

Radio-tracking.—Radio-telemetry, using transmitters from Holohil Systems, Ltd. (Ontario, Canada) and Titley Electronics (New South Wales, Australia) was used to locate diurnal roosts of the bats. The transmitters had frequencies ranging from 150.0–151.9 kHz, and weighed 0.47 g. Hair in the mid-dorsal portion of the bat's body was removed with surgical scissors, and the transmitters were af-

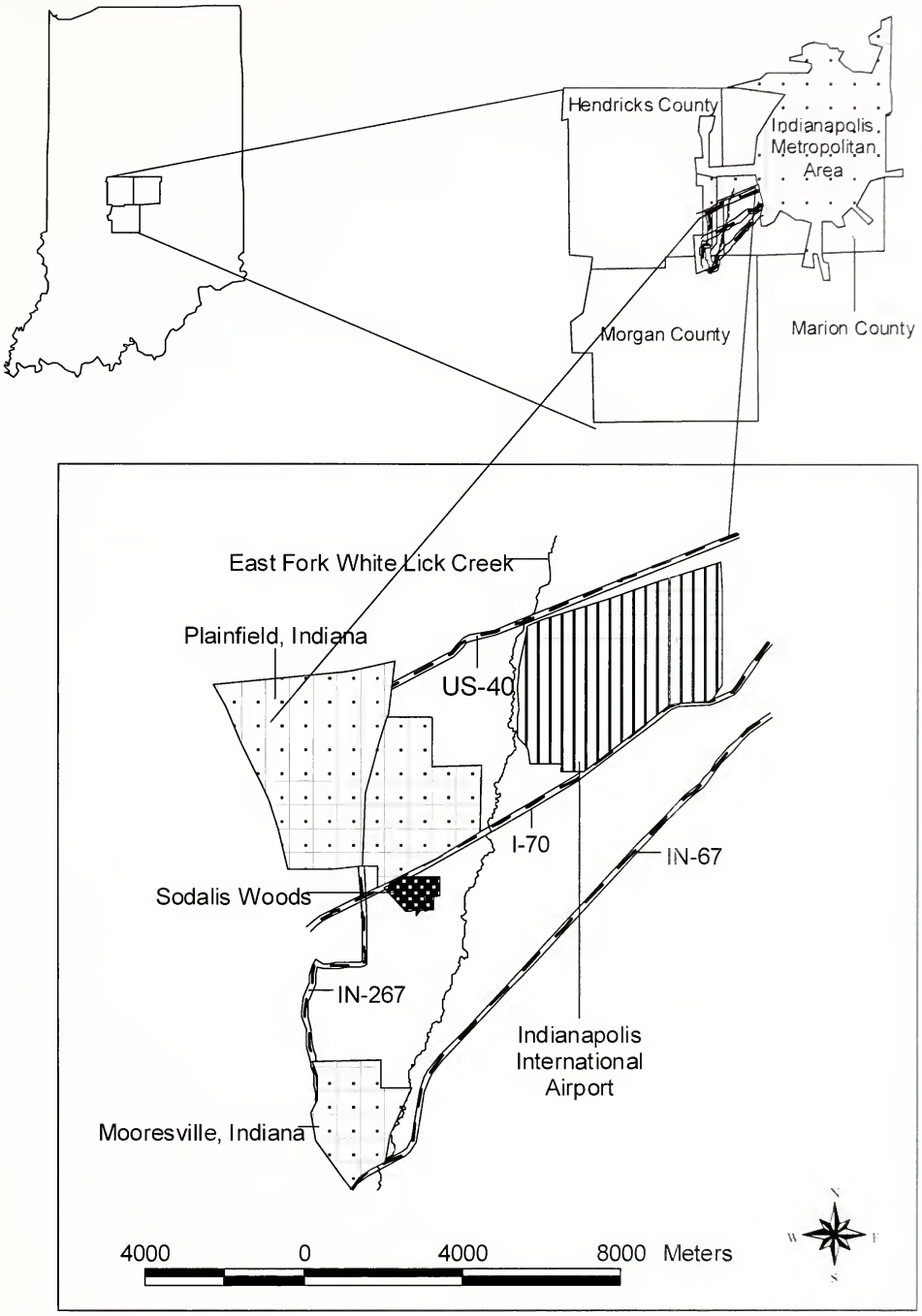

Figure 1.—Major landscape features of the Indianapolis International Airport study site. Stippled areas represent developed (urban, suburban, and commercial) areas. Hashed lines represent major highways and are abbreviated US-40 (US Highway 40), IN-267 (Indiana State Highway 267), IN-67 (Indiana State Highway 67), and I-70 (Interstate Highway 70). Other major features are identified directly on the figure.

Table 1.—Bats taken by mist-netting along the East Fork of White Lick Creek, 1994–1998. No data were collected in 2000 or 2001.

	1994	1995	1996	1997	1998	1999	Total
Species							
Eptesicus fuscus	83	57	20	64	94	74	392
Lasiurus borealis	28	7	1	16	13	23	88
Myotis lucifugus	12	19	3	10	14	13	71
M. septentrionalis	3	15	2	10	3	2	35
Nycticeius humeralis	1	3	1	1	7	15	30
M. sodalis	2	8	2	0	0	10	22
Pipistrellus subflavus	5	4	1	4	2	3	19
L. cinereus	0	1	0	1	0	1	3
Lasionycteris noctivagans	0	0	0	0	0	2	2
Total	134	114	32	106	133	143	662
No. sites netted	10	12	11	10	10	10	—
Avg. no. bats per site	13.4	9.5	2.9	10.6	13.3	14.3	—
No. net nights	30	36	32	30	30	30	—
Avg. no. bats/night	4.5	3.2	1.0	3.5	4.4	4.8	—

fixed with colostomy glue (Skin Bond). TRX-2000s receivers (Wildlife Materials, Inc., Carbondale, Illinois) and R-1000 receivers (Communications Specialists, Inc.) were used to track the bats. Bats were tracked as long as signals were received, or up to six nights.

RESULTS

Bat community.—Numerous artificial roost structures were used at the beginning of these studies, and information collected in 1992 and 1993 consisted mostly of data on bat use of these structures. Systematic collection of biological data by mist-netting commenced in 1994. It supplied information on the bat community and some information on reproduction. Data that year were taken from 2–10 August. Seven species of bats were taken, including the first two Indiana myotis and the first evening bat (Table 1).

Mist-netting.—A total of 781 bats, belonging to nine species, was taken in mist-netting at the airport during the six years since regular mist netting was instituted (1994 to 1999). These captures include 662 bats taken along the East Fork of White Lick Creek (Table 1), 104 bats from 1996–1999 in Sodalis Woods, and 15 bats captured near a second primary roost, a cottonwood, in 1998 (Table 2). Listed in approximate order of decreasing abundance, they are: big brown bat (*Eptesicus fuscus*), northern myotis (*M. septentrionalis*), eastern red bat (*Lasiurus borealis*), little brown myotis (*M. lucifugus*), Indiana myotis (*Myotis sodalis*), evening bat (*Nycticeius humeralis*), eastern pipistrelle (*Pipistrellus subflavus*), hoary bat (*L. cinereus*), and silver-haired bat (*Lasionycteris noctivagans*). This includes all the species of bats at present regularly found in Indiana, except for the gray bat (*Myotis grisescens*), which has one colony in Clark County in southern Indiana.

THE BATS

Big brown bat.—The big brown bat was the bat most commonly taken at the airport, as indicated by 392 (20–94 per year) being netted along White Lick Creek (56.6% of the bats netted there from 1994–1999). Another 47 were netted in Sodalis Woods and 9 near the cottonwood, and it was the most numerous species at both these sites. This is logical since the study area is close to urban areas and this bat inhabits buildings. Relatively few individuals (only 14) were found in the artificial bat structures during regular monitoring. We have located 11 maternity roosts of big brown bats using both radiotelemetry (Duchamp et al. in press) and also visual searches of potential roosts. These roosts have included 1 barn, 2 artificial roosts (bat-houses), 2 bridges, and 6 houses (Fig. 2). In addition, two bridges on the site are commonly used as night roosts by solitary males (Fig. 2). One of these was a maternity roost until the road was resurfaced. Since that time (1999) only males have been found using it as a roost, and big brown bats suddenly began using a series of nearby bat-

Table 2.—Bats netted 1996–1999 in Sodalis Woods near shagbark main tree, and near the cottonwood tree in 1998.

	Sodalis Woods					Cotton-wood tree
	1996	1997	1998	1999	Total	1998
Myotis sodalis	6	3	8	7	24	0
Eptesicus fuscus	0	3	24	20	47	9
M. septentrionalis	0	2	7	0	9	1
Nycticeius humeralis	0	2	4	13	19	1
Lasiurus borealis	0	0	2	0	2	0
M. lucifugus	0	0	1	0	1	3
L. cinereus	0	0	0	0	0	1
Lasionycteris noctivagans	0	0	0	2	2	0
Total	6	10	46	42	104	15

houses. One post-lactating colony of big brown bats was found in a tree (Fig. 2). Pregnant big brown bats (n = 8) were captured at the airport from 20 May through 17 June. Lactating big brown bats (n = 60) were taken from 14 June through 24 July. Post-lactating big brown bats (n = 74) were captured between 9 July and 14 August. Juveniles were captured starting 16 July.

Northern myotis.—The northern myotis is common at IND as indicated by 35 being netted along White Lick Creek from 1994 through 1999, and by its common occurrence in the artificial bat-houses there. It is the only species that regularly uses bat-houses at the airport, and it commonly forms maternity colonies at the study site mostly in the bat-houses. Northern myotis often change roost sites, even taking their young with them. They have also been found in a number of sites (Fig. 3) under sloughing bark, in cavities, in cracks in trees, and in a power pole (Sparks et al. in

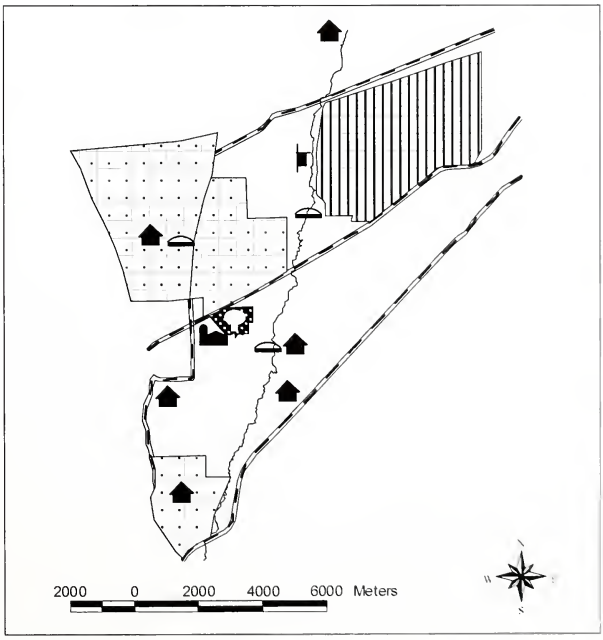

Figure 2.—Roosts used by big brown bats (*Eptesicus fuscus*) near the Indianapolis International Airport. *Symbols:* homes and barns have triangular roosts, barns include a silo, bat-houses have flat roofs, and bridges have curved tops, and the single tree is a white outline inside Sodalis Woods (see Fig. 1).

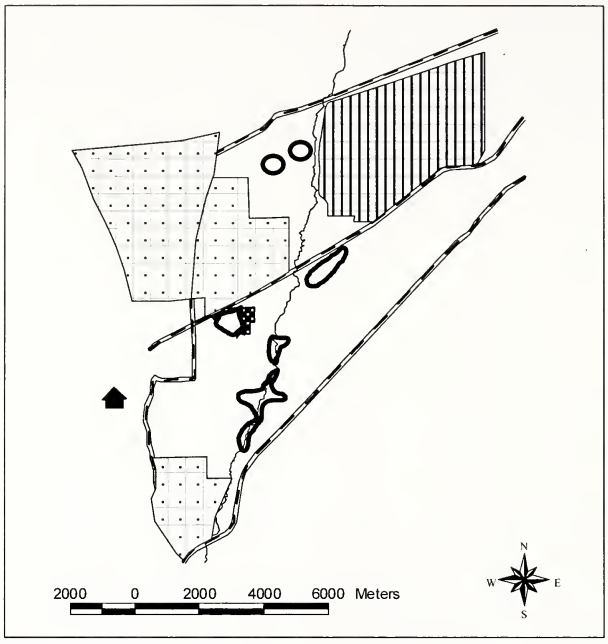

Figure 3.—Roosts used by the northern myotis (*Myotis septentrionalis* the little brown bat (*Myotis lucifugus*) near the Indianapolis International Airport. The symbol with triangular roof represents a house. Northern myotis roosted in a variety of structures. Circular outlines represent the approximate borders between different colonies of *Myotis septentrionalis* determined by radio-tracking. *Myotis lucifugus* was not radio-tracked.

press). Pregnant females were found between 14 May and 26 June (n = 146), lactating females were found from 14 June to 19 July (n = 63), and post-lactating females (n = 26) were found from 2 July through 9 August (n = 13). Juveniles were first seen on 16 July.

Little brown myotis.—The little brown myotis was captured mostly in mist-nets at IND, although two were found in artificial structures. It was surprising that more were not taken in structures as this species nearly always roosts in buildings. A total of 74 little brown myotis was captured by mist-netting, 71 along White Lick Creek, 1 in Sodalis Woods, and 3 near the large cottonwood tree. In 2002, we radio-tracked a female little brown myotis to a barn south of Plainfield and west of Highway 267 (Fig. 3). We suspect that most or all of the little brown myotis caught during the study originated at this site. The landowner indicated that this colony has been present for many years. Pregnant females (n = 7) were observed between 20 May and 15 June, lactating females (n = 10) were observed between 25 June and 14 July, and post-lactating females were captured between 13 July and 11 August. The first juveniles were seen on 24 July.

Indiana myotis.—The Indiana myotis was the target species for this study. The Indiana myotis was first captured on site in 1994 when two individuals were netted. Radio-telemetry in 1996 led to the discovery of the primary roost tree, a dead shagbark hickory in Sodalis Woods (Fig. 4). This tree served as the main roost tree for the species in the study area until it fell over in the winter of 2001–2002. Although this was the principal tree used, dusk counts indicated that many alternate roost trees were used. Also, the large cottonwood was regularly used as a second primary tree in 1997 and 1998 until a major storm caused loss of most of its bark on 29 June 1998. Twenty-two individuals have been captured by mist-net along White Lick Creek and 24 in Sodalis Woods. Pregnant individuals (n = 5) were captured between 3 and 23 June, and 6 lactating individuals were captured between 27 June and 30 July.

Red bat.—Red bats are solitary, having their young among the leaves of trees. They

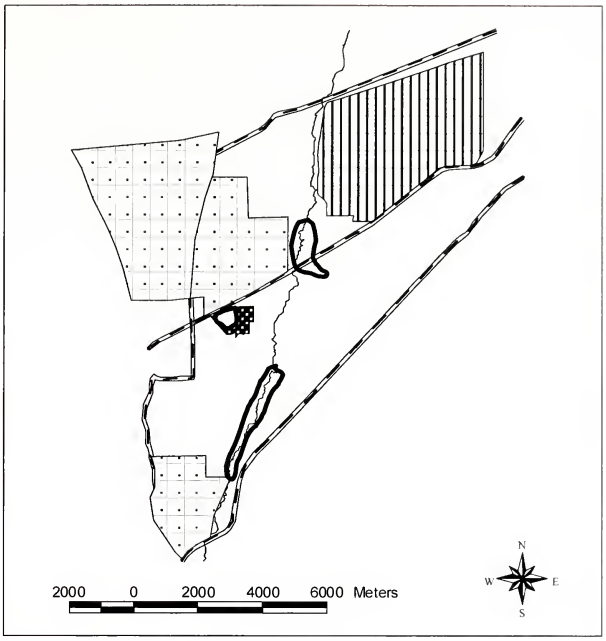

Figure 4.—Roosts used by the federally-endangered Indiana myotis (*Myotis sodalis*) near the Indianapolis International Airport. Three different roosting areas for the one colony present are outlined.

are common in the study area, 88 having been taken in mist-nets along White Lick Creek between 1994 and 1999, and 2 in Sodalis Woods. Lactating individuals (n = 3) were found between 14 July and 11 August, and post-lactating individuals (n = 29) were found between 25 July and 21 August. Brianne L. Everson (pers. commun.) is currently conducting a study of the roosting and foraging of this bat and has located 3 roosting areas to date (Fig. 5).

Evening bat.—Evening bats are listed as state-endangered but not federally-endangered. Evening bats are probably much less common in Indiana than are Indiana myotis (Whitaker et al. 2002). Earlier, all known colonies of evening bats in Indiana were in buildings (Whitaker & Gummer 1993). However, all maternity colonies of this species currently known in Indiana are in tree cavities (Whitaker & Gummer 2003). Most known populations are in the lower Wabash River bottoms from southern Vigo County south, and on the lower White River; but other colonies occur on the upper Muscatatuck River (Jennings County), at Atterbury Reserve Forces Training Center (Bartholomew County) and at IND. We think that evening bats were always in the lower Wabash River bottoms, and that during particularly favorable times they moved up the larger streams and some took up residence earlier in buildings, now in woodlots there. The big brown bat has been increasing in Indiana over recent decades (Whitaker et al. 2002), and may have outcompeted the evening bat for roosts in buildings.

A total of 30 evening bats was caught during mist-netting of White Lick Creek from 1994 through 1999 (Table 1). Also, 19 individuals were captured in Sodalis Woods.

An evening bat was captured on White Lick Creek in 1997 and was radio-tagged. It was tracked to a roost in an American beech (*Fagus grandifolia*) in a woodlot north of I-70 on 1 August 1997 (Fig. 6). It was in the same tree on 16 and 17 August, and a dusk count on 17 August yielded three animals leaving that tree. In addition, 10 others emerged from a nearby tree. Numerous calls of evening bats were heard in this woodlot. It was clear that the evening bats inhabited this woods in 1997. The woodlot with the evening bats in 1997 was almost due north of the Indiana bat maternity roost. This woodlot was clear-cut in the winter of 1997–98 (Sparks et al. 1998). The evening bats then moved to Sodalis Woods.

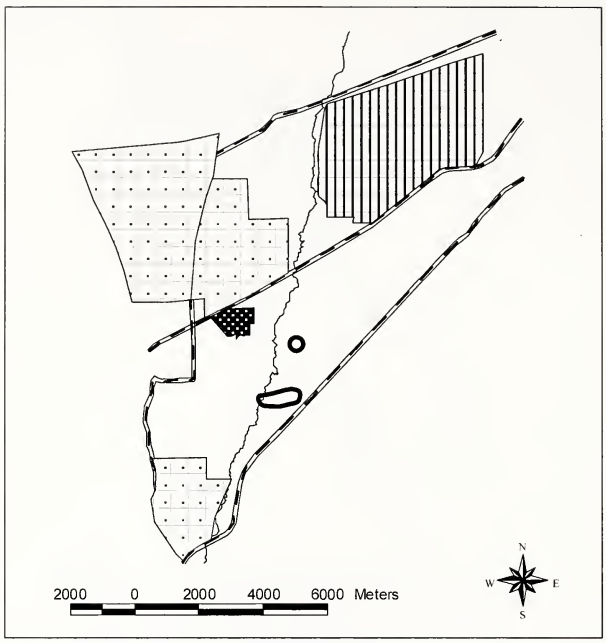

Figure 5.—Roosts used by the eastern red bat (*Lasiurus borealis*) near the Indianapolis International Airport. Two roosting areas are outlined.

No evening bats were taken in 1996, the first year of netting there, whereas 2, 4, and 13 captures occurred in 1997–1999, respectively. Roosts were located in tree cavities in a variety of species of trees.

We have tracked evening bats to 14 trees in Sodalis Woods and to other woodlots south of Interstate 70 (Duchamp et al. in press). Five species of trees were used: shagbark hickory (*Carya ovata*, 5 trees), red oak (*Quercus rubra*, 3), sugar maple (*Acer saccharum*, 2), bitternut hickory (*Carya cordiformis*, 2), white oak (*Quercus alba*, 1), and green ash (*Fraxinus pennsylvanicus*, 1). All evening bats roosted in tree cavities, and numbers counted at emergence ran from 2 to 100.

Five lactating evening bats were captured between 25 June and 8 July; three post-lactating individuals were captured between 12 July and 11 August and the first juveniles were seen on 3 August. No evening bats were ever observed in buildings or artificial structures.

Silver-haired bat.—This species does not reproduce in Indiana, but migrates to its summering grounds to the north in spring (Mumford & Whitaker 1982). One silver-haired bat was taken in a bat structure on 18 June 1993. Two additional silver-haired bats were netted on 17 June 1999. These records are later than is typical for migrating silver-haired bats in Indiana. We radio-tagged one of these bats. On 18 June it day-roosted under the bark of a shagbark hickory in Sodalis Woods and then disappeared immediately after emerging. These data, combined with the absence of subsequent captures, indicate that this bat was simply a late migrant.

Hoary bat.—The hoary bat is solitary and relatively uncommon. Like the red bat, this species roosts among the leaves of trees. Four were netted at the study site from 1994 through 1999, three along White Lick Creek, and one near the cottonwood roost. One taken on 28 July 1997 was a juvenile, and a post-lactating female was netted on 12 July 1998. In 2002, a juvenile male was radio-tagged and tracked to roosts along the East Fork of White Lick Creek (Fig. 7).

Eastern pipistrelle.—The eastern pipistrelle sometimes forms small maternity colonies in buildings (Whitaker 1998) but more often lives in woods where it roosts singly or in very small numbers in clusters of leaves (Veilleux et al. 2003). Nineteen individuals were netted at IND along White Lick Creek. Four

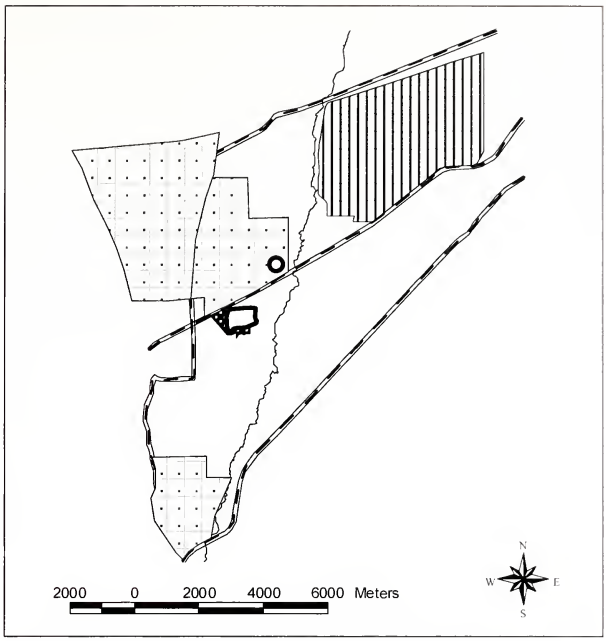

Figure 6.—Roosts used by the state-endangered evening bats (*Nycticeius humeralis*) near the Indianapolis International Airport. In 1997 the colony roosted in an area north of Interstate Highway 70, and then moved into Sodalis Woods when the original roost was cut. Both areas are outlined.

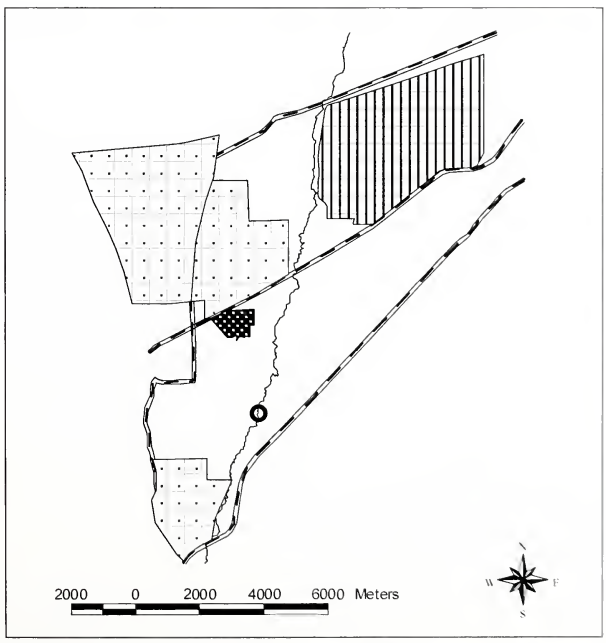

Figure 7.—Roosts used by a hoary bat (*Lasiurus cinereus*) near the Indianapolis International Airport. Three trees used by a single hoary bat are outlined.

lactating individuals were captured between 5–16 July.

DISCUSSION

It is interesting that this site still hosts all nine species of bats that could reasonably be expected there (Mumford & Whitaker 1982), and eight produce young there. This is especially interesting since there is so little woodland, and since the area is being so drastically developed. It is possible that this is a result of being crowded into the site as the surrounding areas are developed. In the north end of the area, much of what was natural area at the beginning of this study, including some excellent woodland habitat for bats, has now been developed and consists of roads, large warehouses, mowed grass and open ponds. However, the number of bats captured in the mist-nets may seem small. This may be partly because of the relatively small amount of forest near the airport. Another reason may be the limited amount of canopy available along the East Fork of White Lick Creek. Limited cover may reduce numbers of bats captured in mist-nets because the bats can more easily maneuver to avoid capture. These data do give the best baseline data for later comparison to help determine the future status of the bat community at the airport.

Roosting areas of the bats at IND are indicated in Figs. 2–7. Big brown and little brown bats are in human structures, thus do not conflict with the other species for roosts. However, all of the woodland bats are concentrated in the area south of I-70, particularly the Sodalis Woods. Indiana myotis, northern myotis, and evening bats all roost in this area. There are other areas where Indiana myotis roost, particularly along the East Fork of White Lick Creek (Fig. 4), but evening bats currently roost only in that area. Northern myotis, however, are much less restricted and occur in several other areas. Current information on red and hoary bats is more limited (Figs. 5, 7), but those species are the subjects of current study. We suspect that red bats, at least, probably roost throughout much of the study area.

That the bats are able to survive is probably due in part to the variation in the summer roosting habits of the female bats. The silver-haired bat spends the summer north of Indiana, whereas the remainder of the species live in summer in Indiana. Red and hoary bats occur in Indiana in summer among the foliage of trees. Eastern pipistrelles roost in clusters of leaves (Veilleux et al. 2003). Big brown bats and little brown bats, especially the former which is the most common species on site, use human structures. The evening bat previously often used human structures, but now uses cavities in the trunks or larger limbs of trees, old woodpecker holes and the like, but not necessarily in the sun. The Indiana myotis has the most specialized maternity roost requirements, normally using fairly large trees with areas of sloughing bark open to the sun. The northern myotis is the most variable of these species in maternity roost choice. It is primarily a forest species and will roost in or out of the sun, and roost in cracks of broken-off trees, or in other protected areas besides using sloughing bark or cavities. In addition, this is the only species regularly using the bat-houses.

Another possibility as to why bat diversity at IND is so great is that the bats are so loyal to an area and are so long-lived that they keep coming back each year. However, it is possible that they are actually slowly dying out in this area because of decreasing suitable habitat and/or increased competition with other species. The evening bat is the most likely species at risk. It has already been forced out of one area and it now roosts and forages in a small area between Sodalis Woods and the airport (Duchamp 2002).

The Indiana myotis and evening bat are the two species that seem most in conflict, not so much because of competition for roost sites, since one uses cavities and the other sloughing bark, but because they both currently have their centers of activity in the same woods, and there is much interaction of the two here. We have even seen some evidence of actual roost sharing as bat parasites are very host specific, and we have seen three bats that have had parasites of one of the other species (Ritzi pers. commun.). As indicated above, *M. sodalis* roosts primarily under sloughing bark. However, both *M. septentrionalis* and *Nycticeius* will also sometimes roost under sloughing bark. Therefore, they could be subjected to increasing competition for roosts in this situation where *Nycticeius* has invaded the Sodalis Woods and natural woodland habitat has continued to decrease. Fortunately their food

habits are quite different, with the evening bat feeding primarily on beetles, true bugs and few moths, whereas the Indiana myotis feeds heavily on moths, smaller beetles and dipterans (Mumford & Whitaker 1982; Whitaker 2004).

Although the woods have continued to decrease dramatically near the airport over the last decade, conservation efforts are underway at IND. As much woodland as possible is being preserved, and new woodlands and ponds have been created. IND has already replanted about 160 ha to trees. The woods are still very young, but the ponds are already the best area in the vicinity for reptiles and amphibians (Foster et al. 2004). Overall, IND is creating a suitable natural area southwest of Indianapolis for many kinds of plants. Bats may be currently stressed at IND because of the relatively small amount of woodland for roosting, but it will be very interesting to see over the following decades how well the bat community does—especially the Indiana myotis and evening bat.

ACKNOWLEDGMENTS

The authors are indebted to the Indianapolis International Airport and the Indianapolis Airport Authority for funding and for other support during the course of this project. Particular thanks are extended to M. Brethauer for help and support throughout the study. J.L. Chew, B.L. Emery, J.K. Farrell, B.J. Foster, C.L. Gummer, S.L. Gummer, J.A. Laborda, M.T. Slater, E.R. Stinson and W.A. Ulrey participated in collection of the data.

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GENDER DIFFERENCES IN PARENTAL FEEDING EFFORT OF CERULEAN WARBLERS AT BIG OAKS NATIONAL WILDLIFE REFUGE, INDIANA

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ABSTRACT. As part of a broad study on Cerulean Warbler (*Dendroica cerulea*) breeding biology in southern Indiana, we examined parental feeding bouts. We hypothesized that females would feed nestlings more often than males, based on documented behavior of several closely related *Dendroica* warblers. Cerulean Warbler nests were observed for one hour every other day from hatching to fledging. Differences in frequency of feeding trips between males and females were recorded. Our hypothesis was supported; females were significantly more likely than males to feed nestlings at four nests.

Keywords: Cerulean Warbler, *Dendroica cerulea*, feeding bouts, parental investment, Indiana

The Cerulean Warbler (*Dendroica cerulea*) is a Neotropical migrant that has experienced overall steady population decline, as much as 3.4% per year, between 1966 and 1996 (Hamel 2000; Robbins et al. 1992). It winters in the Andes of northern South America but returns to breeding areas in North America in early May (Hamel 2000). The breeding range extends throughout the northeastern and midwestern regions of the United States and as far north as Ontario and Quebec in Canada (American Ornithologists' Union 1998; Hamel 2000). Cerulean Warbler populations have been decreasing for decades, with most of the dramatic losses having occurred during the last 30 years (Jones et al. 2001; Hamel 2000; Robbins et al. 1992).

Cerulean Warbler habitat has declined in the midwestern United States in recent years. Possible factors in the decline include loss of deciduous forest overall, habitat fragmentation, loss of key tree species, and a changing forest management regime (Hamel 2000). One consequence of habitat decline (due to increased urban sprawl) is a reduction of large tracts of mature hardwood forests, specifically in the midwestern United States (Indiana north to Quebec) (Jones et al. 2001). Urbanization, leading to increased habitat fragmentation, has left Cerulean Warblers more concentrated in the few remaining larger tracts of mature forests.

As part of an ongoing long-term study on the breeding biology of Cerulean Warblers, we investigated the role of parental investment as it relates to differences between sexes in frequency of feeding trips. Hamel (2000) stated that both sexes are present during nestling rearing. Initially, the male provides greater feeding effort with the female's proportion of the workload increasing later as she shifts from brooding to feeding. Currently only one study (in southeastern Ontario, Canada) has examined parental feeding bouts in Cerulean Warblers (Oliarnyk & Robertson 1996).

STUDY AREA

Big Oaks National Wildlife Refuge (NWR) is located in Jefferson, Jennings, and Ripley counties in southern Indiana (Fig. 1). This refuge contains over 20,000 ha of various habitats, including mature mixed hardwood forest. This type of habitat is critical to breeding Cerulean Warblers, which have been shown to occur there since 1990 (Bruner 1998).

METHODS

Nests were located beginning in early May 2003, and nest searching concluded in early July when no additional active nests were located. Cerulean Warbler females have characteristic nest-leaving behavior described by some as "bungee jumping," or deep dives when leaving the nest (Jones & Robertson

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Figure 1.—Location of Big Oaks National Wildlife Refuge in Jefferson, Jennings, and Ripley counties in southern Indiana.

2001). Other behaviors (nest construction, males delivering food to incubating females, females moving to and from nest during incubation, and the calls of nestlings) were also used to find nests. Similar methods are described in Jones & Robertson (2001) and Oliarnyk & Robertson (1996). Observations were recorded every second day from the time nests were located until young fledged or nests failed. Every nest was observed from the ground with a spotting scope for 1 h in the morning at variable times after sunrise (0600–0900 h).

Parental feeding bouts and the amount of time females spent brooding were recorded during each observation period. Each trip by a parent successfully delivering food to nestlings was equal to one feeding bout regardless of duration. Nestling age was determined in one of two ways. At nests located prior to hatching, observations were made of the incubating female until she and/or the male started bringing food to nestlings. If the nest was located after hatching, observations were made until fledging or nest failure and then age of the nestlings was calculated. If the age of nestlings was unknown, it was possible to calculate back from the time the nest was found to fledging of the young (Oliarnyk & Robertson 1996). Young typically fledge 10–11 days after hatching (Hamel 2000).

The weather was unseasonably cool for several weeks after nesting had begun and likely chilled eggs. This factor, combined with predation, resulted in only 7 of 26 clutches actually hatching and providing data on parental feeding (Roth 2004). Our best comparison of parental feeding bouts was of four nests with data collected on the sixth day after hatching. These four nests were compared using paired *t*-tests (LeBlanc 2004). Analyses was conducted using SPSS for Windows (V11.0.1, 2001) at $\alpha = 0.10$.

RESULTS

Females were found to brood for an average of 37.3 mins per h ($n = 3$; Table 1). In some instances, males were seen feeding the female on the nest while the female was brooding. Sometimes both sexes fed young simultaneously while, at other times, a female would move to the edge of the nest while a male fed the young. Generally, both parents did not feed nestlings at the same time. Females fed nestlings more often than males (mean feedings/h ± SE; males = 1.5 ± 0.75, females = 4.0 ± 2.0, $n = 4$, *t*-value = 2.89, *P* value = 0.063; Table 1).

Parents were seen either feeding nestlings separately or males feeding females with the female delivering food to nestlings. In some situations, females perched on the side of the nest while the male fed nestlings. These observations of adults feeding nestlings are similar to those observed for Prairie Warbler (*Dendroica discolor*) (Nolan 1978).

DISCUSSION

There was a significant difference between female and male feeding rates (*P* value = 0.063; Table 1). Females were still spending a great amount of time brooding (37.3 minutes/hour) on the sixth day after hatching.

Lovette & Bermingham (1999) conducted molecular analyses of *Dendroica* warblers. Based on their results of the phylogenetic relationships, Cerulean Warblers are alone in one clade; thus, we have chosen to make comparisons with the clade most closely related to the Cerulean Warbler.

In Black-throated Blue Warblers (*Dendroica caerulescens*), females fed nestlings more

Table 1.—Comparison of gender differences in feeding bouts of Cerulean Warblers (*Dendroica cerulea*) between southeastern Ontario, Canada in 1996 (Oliarnyk & Robertson 1996) and Big Oaks National Wildlife Refuge, Indiana in 2003.

	Southeastern Ontario, Canada (1996)	Big Oaks NWR, Indiana (2003)
Age of nestlings for data being reported	Averaged for entire brooding period	Day 6 post-hatching
Nest sample size	8	4
Male feeding bout (mean feedings/h ± SE)	3.5 ± 1.81	1.5 ± 0.75
Female feeding bout (mean feedings/h ± SE)	3.5 ± 3.7	4.0 ± 2.0
Average female brooding time (min/h)	49.2 (n = 5)	37.3 (n = 3)
Paired t-Test	Not used	t-value = 2.89 P value = 0.063

often than males (Chuang-Dobbs et al. 2001), although Holmes (1994) reported no differences in number of feeding bouts between the sexes. In Prairie Warblers (Nolan 1978), females also fed nestlings more often than males. In contrast, Hunt & Eliason (1999) reported no difference between feeding bouts of males and females in Blackpoll Warblers (*Dendroica striata*).

In their study of Yellow Warblers (*Dendroica petechia*) Yezerinac et al. (1996) reported that males fed nestlings more often than females. This same pattern was reported in Chestnut-sided Warblers (*Dendroica pensylvanica*) (Richardson & Brauning 1995) and Magnolia Warblers (*Dendroica magnolia*) (Hall 1994).

Oliarnyk and Robertson (1996) reported no difference in number of feeding trips by male and female in Cerulean Warblers for eight nests; however, they produced no day-specific analysis on feeding bouts. While our field methods were similar to theirs, we did find a significant difference for four nests on the sixth day post-hatching. Because both studies used very similar methods, questions arise as to the source of the difference in results (Table 1).

We considered two explanations for the difference between the results of this study and that of Oliarnyk & Robertson (1996). There may be a temporal (time of day) difference between frequency of feeding trips of males and females. But neither study investigated evening feeding bouts; therefore, this explanation is not valid. Many species increase feeding effort as the nestling period progresses. During this increase, the female most likely changes her workload from brooding to an increasing number of feeding bouts while, at the same time, the male decreases his feeding bout rate. One difficulty in making this comparison is that the majority of published studies only report overall feeding bout rates while disregarding day-to-day comparisons (e.g., Oliarnyk & Robertson 1996). Only additional research which examines and reports day-to-day differences over the brooding period will answer this question.

Many avian studies examine feeding bouts but present only an average feeding frequency for the entire nestling period. These analyses are incomplete. Perhaps many species have been reported as having no difference between feeding frequency for males and females when, in fact, there may be a temporal difference. Feeding bout research needs to address this problem by making more complete analyses and reporting day-to-day comparisons. In order to tease apart individual roles of each parent, daily differences must be investigated and reported to allow for the best possible conclusions. This would allow a more complete understanding of the behaviors of breeding biology and how they change over time.

ACKNOWLEDGMENTS

The Indiana Academy of Science and the United States Fish and Wildlife Service funded this research. We thank Joe Robb, Refuge Manager of Big Oaks National Wildlife Refuge for providing logistical support, as well as guidance, in the field. Thanks to David LeBlanc for supervision of statistical analyses. Kirk Roth and Jason Jones provided guidance, support, and encouragement. Kelly Jones and

the rest of the field assistants helped immensely with data collection. This manuscript has benefited from the comments and suggestions of J. Dan Webster, Jim Berry, and an anonymous reviewer.

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Manuscript received 8 May 2004, revised 1 September 2004.

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